REFINER
AND NATURAL GASOLINE MANUFACTURER

JUNE, 1940
Vol. 19, No. 6

A Gulf Publishing Company Publication
EDITED MONTHLY AT HOUSTON, TEXAS

Copyright, 1940

GRADY TRIPLETT
Editor

CONTENTS

Selection of the Most Economical Pipe and Valve Size and Rate of Flow in Piping Systems 53
S. P. Johnson and F. L. Maker

Application of Superheated Steam in Combination Unit Prime Movers 65
A. E. Harnsberger

Some Variables in Filter Clays 69
L. M. Henderson, C. M. Ridgway and W. B. Ross

Removal of Sulfuric Acid Fog by Bubble Phase Absorption 75
D. W. Bransky and F. F. Diwoky

Testing of Non-Ferrous Alloys for Condenser-Tube Service Under Conditions Simulating Actual Industrial Service ... 80
R. W. Moore and S. Kleinheksel

Cathodic Protection of Condensers and Coolers Utilizing Brackish Bay Waters 86
W. A. S. Wright and J. H. Brooks

Significance of the Doctor Test for Gasoline 89
John Happel and S. P. Cauley

Knocking Octanes 93
H. W. Field and C. H. Van Hartesveldt

Elimination of Hydrate Troubles 99
E. G. Hammerschmidt

Elements of Vaporization—Part V 103
R. L. Huntington

Chemical Removal of Scale from Refinery Equipment 106
L. W. Lee

Surplus Gasoline and Smaller Exports Handicap Industry 110
L. J. Logan

Departments

Look Box .....51 and 121

Plant Activities 132

Science and Technology—Abstracts 136

New Equipment 144

Business Notes 152

Catalogs and Bulletins 156

Advertisers' Index 162

SPECIALIZED OIL JOURNALS

Published by
THE GULF PUBLISHING COMPANY

OFFICE OF PUBLICATION
3301 Buffalo Drive, Houston, Texas

R. L. DUDLEY, *President*
A. L. BURNS, *General Manager*
S. W. ROBINSON, *Editorial Director*
J. KENT RIDLEY, *Managing Editor*
TOM W. NELSON, *Advertising Manager*

NEW YORK: Room 625, 250 Park Avenue, Dick Swinsky, Manager.

PITTSBURGH: 72 Vandergrift Building, Chas. A. Wardley, Manager.

CHICAGO: 332 S. Michigan Avenue, H. G. Fitzpatrick, Manager.

LOS ANGELES: 425 W. W. Wilson Building, Huntington Park, California, Jay Curts, Jr., Manager.

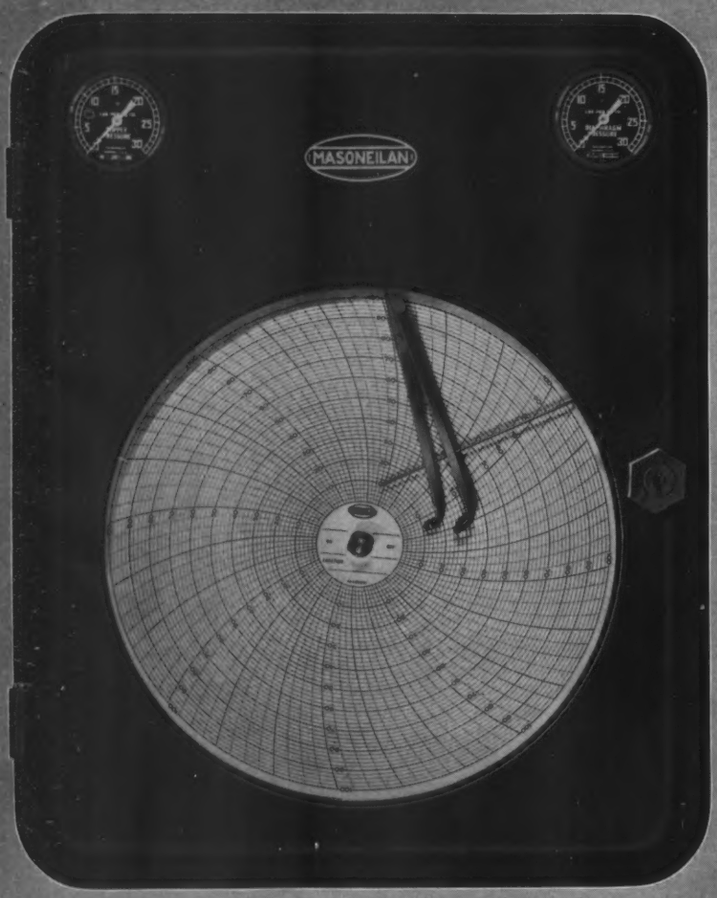
TULSA: 1304 Hunt Building, J. F. Carter, Jr., Manager.

FT. WORTH: 203 W. T. Waggoner Building, H. H. King, Manager.

Single copies 20 cents. Special issues single copies 50 cents. Domestic subscription price $1.00 a year. Canada and Foreign subscription price $2.00 a year. Entered as second class matter June 16, 1923, at the post office at Houston, Texas, under act of March 3, 1879. Advertising rates on application.

Copyrighted 1940 by The Gulf Publishing Company.

Introducing



Above: **THE RECORDING CONTROLLER**—styled in accordance with advanced mechanical features and modern panel layouts. Compact yet roomy enough for the most complex control assemblies.

At Right: **THE INDICATING CONTROLLER**—compact, streamlined finely proportioned case; airplane type, non glare dials and straight line indicating scale; universal mounting.

VOLUME 19, No. 6 JUNE, 1940

REFINER
AND NATURAL GASOLINE MANUFACTURER

A Gulf Publishing Company Publication

The Look Box

EVIDENTLY gaining economy under public ownership is akin to steering a skiff in a whirlpool. The turbulence in the Mexican oil industry is such that men should await the outcome before clamoring for control of any industry by government.

South of the Border

From north of the border our own state department has been putting on pressure to gain arbitration of claims of American concerns, whose properties were taken over by the Cardenas government. Its promises have indicated that payment would be made from profits of the industry.

In late April, however, the Mexican government served notice on the Petroleum Workers Union to reorganize the industry to gain economy and efficiency. Evidently profit within the industry is remote, which would indicate that payment from that source is doubtful.

Cardenas had proposed changes which included reduction of the number of workmen, wage reductions, abolition of some employe benefits, elimination of unnecessary jobs and restrictions on union autonomy.

It was to gain higher wages as well as other benefits that the Mexican government took over private industry.

The government has announced improvement in Mexican motor fuel to the point that the summer will bring 70 octane gasoline, an accomplishment hailed as an inducement to American tourists.

Perhaps settlement of the expropriation issue will come when Mexican labor learns that highest wages come from private ownership and management.

BACK in 1925 refining a barrel of crude oil required fuel consumption of 1,045,000 B. T. U. By 1938 a barrel of crude oil went through refining on heat energy of 554,000 B. T. U. This comparison is from the report of Bruce K. Brown,

Progress Measured by Heat and Dollars

Standard Oil Company (Indiana) before the American Chemical Society in Cincinnati, who also contrasted the two years on an investment basis with:

"The technical advances in refining have been such that in contrasting 1925 with 1938, the same

capital invested in refining results in a plant which will produce twice as much gasoline."

WHILE one branch of government threatens to prosecute the petroleum industry for violations of the anti-trust statutes, another makes ready to demand that all industry draw itself into drastic monopoly as a part of military defense. The inconsistencies of Washington can be no better drawn than this prospect for the petroleum industry.

Prosecution Could Wait

Violations of the anti-trust statutes should be prosecuted, oil included. Whether the oil industry has violated these laws is yet to be proved, so the industry should not be stamped as guilty previous to its day in court.

The inconsistency comes about in the timing of the moves by government. If the oil industry plays its role in a defense program it must, at the behest of government, become a monopoly of the sort it could neither imagine nor accomplish without the urging of government. While it is engaged in reaching such a status, it cannot prepare itself against charges that it already has become a violator of existing laws.

Under the demand to help in the defense of a country, it will be hampered in preparing a defense for itself.

Perhaps it is too much to expect the executive and the justice departments to cooperate under such circumstances, still it would seem like good policy for the Attorney General to be told to withhold his charges until the President has had what he needs out of the oil industry. That course might speed the defense program so far as oil is concerned.

WHEN the federal government was casting about for added revenues in 1932, petroleum products were out in the open and without protection.

Taxes were levied and classed as "temporary." Early in April the total collections from automobile owners passed $2,000,000,000 from these "temporary" laws.

Temporarily Permanent

The part that comes through avenues of the petroleum industry is finally paid by the automobile owner, a fact the consumer seems to overlook.

It is not industry that is taxed, except indirectly. The consumer of merchandise pays all taxes levied against it, regardless of what records may show.

IN HIS BOOK, "Smoke Screen," Samuel B. Pettengill pays tribute to the petroleum industry as an example of conservation as a part of private enterprise. The former Indiana Congressman has written on a theme to the effect that the trend in national government is toward national socialism. He selected oil and the automobile as examples of what industry can accomplish when not hampered by government.

Research Credited With Conservation

His charge is that the greatest waste known to the petroleum industry was made possible by government, the court decision whereby the law of capture became a precedent. He cites the fact that the industry has sought to change the law of capture without success and adds:

"But the industry has done more. It has invested tens of millions of its own money in research to prevent waste, above and below ground. Let me mention one, cracking, a new method for the refining of gasoline from crude petroleum. In the 18 years, 1920-1938, the industry ran 15,633,720,000 barrels of crude to the refining stills. From it, 6,143,216,000 barrels of gasoline were refined by cracking. If the cracking process had not been used 26,800,626,000 barrels of crude would have been necessary to produce the same amount of gasoline.

"This means, in effect, that the industry saved or conserved by the cracking process, 11,166,906,000 barrels of crude which otherwise would have been consumed to provide fuel for our motor transport. As the process has been constantly improved, today, by cracking, 52.42 percent of every barrel of crude oil is saved.

"Just what is 11,166,906,000 barrels of oil saved? From 1857-1938 the United States, producing 64 percent of world's total produced 21,187,141,000 barrels of crude. So in effect the industry, in its research laboratories, have found more than half as much crude in 18 years as has been brought out of the bowels of the earth in 80 years. Another way of stating it is that this practical saving has been twice as much as all oil produced in Texas —the Golconda of Black Gold—in its entire history. One test tube = two times Texas!

"But do these national socialists in Washington give the industry any credit for saving 11,000,000,000 barrels of oil? No. They do not. On the contrary they want leave of Congress to tell the industry how to run its affairs. A gentleman, who admitted before my old committee that he had never seen an oil well before he entered the cabinet, has now learned enough in his swivel chair at Washington to manage not one oil company but all companies."

Selection of the Most Economical Pipe and Valve Size and Rate of Flow in Piping Systems

By S. P. JOHNSON and F. L. MAKER
Standard Oil Company of California, San Francisco

THE size of long pipe lines usually is determined by balancing pipe cost against pumping cost. As a formal economic study for each element of a plant piping system would be out of the question, various shortcut methods commonly are employed, the most usual being to assume a reasonable velocity or a reasonable pressure drop on the basis of experience or common sense. This paper examines these methods, and shows that they are apt to err when the density or viscosity of the fluid is unusual or when special materials are required. A rational method of selecting pipe size for any fluid is worked out, and charts are included which permit the economic selection of size to be made with a minimum of calculation.

It is shown that valves, and sometimes other appurtenances, are not necessarily best made the same size as the line. The economy of small-size valves has been worked out, and suggestions are made for installation.

The flow rate in a piping system usually is dictated by process requirements or basic assumptions. There are, however, interesting exceptions when the designer of the piping must choose the flow rate as well as the pipe size to secure the lowest overall cost. One of the most important problems of this class arises in designing a loading system for tank ships, tank cars, or trucks when a three-way balance should be struck between pipe cost, pumping cost, and cost of delay. This problem is simplified by the development of a chart showing the most economical flow rate for any given or assumed loading system.

This paper was presented to Division of Refining, before the Tenth Mid-Year Meeting of the American Petroleum Institute, Fort Worth, Texas, May 29, 1940.

PIPING represents a major item of cost in oil-refining plants and, for that matter, in almost all process and power equipment. The proper design of piping systems demands imagination and common sense, as well as a thorough appreciation of the requirements to be met and a considerable amount of experience. The phase of the subject covered by this paper is limited to the proper choice of pipe size which, if seemingly not an inspiring topic, is certainly fundamental, and one by no means always attacked by rational methods.

Long transmission lines for oil and gas usually receive extended and individual design studies. It is not the purpose of this paper to trespass on this important subject, but to deal with short process and transfer lines and, incidentally, with other comparable lines such as those in gas or oil-gathering systems. In laying out such systems, the time required to make detailed economic studies for each line is prohibitive, and shortcut methods necessarily are followed. These methods are satisfactory if backed by previous calculation or experience. However, it seems well worthwhile to establish a general shortcut method that does not rely on individual experience and intuition. This approach is particularly valuable when one has to deal with a diversity of conditions. The two commonest shortcut methods may be examined briefly. They are:

1. *The allowable pressure-drop method:* In this method a pipe size is selected that gives what the designer considers to be a reasonable pressure drop. Common sense tells him, for example, that it is not reasonable to use up a large fraction of the static pressure in a high-pressure process system in pumping fluid through a few feet of connecting piping. Furthermore, many studies have shown that rates of pressure drop must be held within certain limits that may be kept in mind or recorded for reference. This method, however, is not rational, because the economical rate of pressure drop is considerably greater in small pipes than in large ones. For a given fluid, a constant pressure drop means that the rate of discharge will vary as perhaps the 2.6 power of the diameter, whereas for best economy it should vary about as the 2.15 power. Also, constant pressure drop means that the mass-discharge rate will vary as the square root of the density of the fluid, whereas it should vary as the ⅔ power. This method does have the advantage at least of recognizing fluid density as a factor to be considered, and of making allowances usually within gunshot of the truth. It does not recognize directly that the cost of fluid energy dissipated by friction is subject to variations of as much as 10 to 1, although fortunately this factor affects the proper discharge rate only as the cube root.

2. *The reasonable velocity methods:* This method is used often, and works very well for any well-known fluid with which the designer is familiar, such as water or steam. It takes no direct account of density —although actually the proper velocity, other things being equal, varies inversely as the cube root of the density. It indicates that the mass-discharge rate should vary as the square of the pipe diameter, when it really should vary about as the 2.15 power; but it will be observed that this is a much closer approximation than the constant pressure-drop method provides. If the cost of pipe is directly proportional to the diameter, and if the friction factor in the common formula for fluid friction is independent of pipe diameter, then—other things being constant—constant velocity for all pipe sizes is correct. These con-

ditions sometimes are realized approximately for insulated lines.

The reasonable velocity method is to be recommended over the pressure-drop method if separate allowance is made for density and economic factors.

Neither of these methods takes any direct account of changes in costs, which sometimes are quite important. These can be accounted for only by considering the problem on the basis of economics. The following treatment is not claimed to be especially novel, but it is hoped that it presents the results in a form that will be found convenient for practical use.

Formulas for Economic Size of Lines

In this development, an absolute system of physical units will be supposed. The flow will be assumed to be turbulent—although the same treatment would apply for viscous flow. The required constants for commercial units will be inserted later. The same notation will be used, irrespective of the units employed, but the units used will be stated carefully. The foot, pound-mass, second, system will be presumed at the end; but the work would be the same in the foot, slug-mass, second, or cgs [1] systems. One of the most generally accepted forms of the expression for friction loss in a pipe line is:

$$p' = f\rho \frac{1}{D} \frac{v^2}{2}$$

Where:

p′ is the pressure lost by friction in length *l*.
f is the friction factor, which is sometimes called λ.
ρ is the density of the fluid.
D is the diameter of the pipe.
v is the mean velocity.

If we insert in this formula the value of the velocity in terms of the mass rate of flow, *M*, it becomes:

$$p' = \frac{8}{\pi^2} \frac{flM^2}{\rho D^5}$$

The fluid power dissipated by the pressure loss *p′*, which is denoted *E*, is the product of the pressure loss by the volume rate of flow; i.e.:

$$E = \frac{M}{\rho} p'$$

(If the fluid is compressible, this properly should be stated only in differential form:

$$dE = \frac{M}{\rho} dp'$$

ρ being variable.

However, as a usual thing, the pressure drop in pipes conveying gases about a plant is but a minor fraction of the static pressure. In such cases the following development, which neglects expansion, will apply for either gases or liquids, provided some discretion is used in interpreting the results.)

If the unit cost of an increment of power-generating machinery is *k*, if *r* is the rate of fixed charges on such machinery, and if *c* is the incremental operating cost per absolute unit of energy, and *t* the number of seconds a year the equipment operates, the annual cost of power for pumping is:

$$V_E = (rk + ct) E = \frac{8}{\pi^2} \frac{fl\,(rk + ct)}{D^5} \frac{M^3}{\rho^2}$$

The cost of pipe may be expressed conveniently as a function of some known size, the cost of which the designer may keep in mind and use as a base of reference for different conditions. Suppose the unit cost of this reference size is P_0, then the annual cost of the pipe line:

$$V_L = lrP_0\, \phi(D)$$

where: φ is a function to be determined. The total annual cost, being the sum of the power and pipe cost, is:

$$V = \frac{8}{\pi^2} \frac{fl\,(rk + ct)}{D^5} \frac{M^3}{\rho^2} + lrP_0\, \phi(D) \quad \ldots\ldots (1)$$

For *V* to be a minimum, its first derivative with respect to *D* should vanish: [2]

$$\frac{dV}{dD} = \frac{8}{\pi^2} (rk+ct)\, l \frac{M^3}{\rho^2} \left(\frac{1}{D^5} \frac{df}{dD} - \frac{5f}{D^6} \right) + rP_0 l \frac{d\phi}{dD} = 0 \quad \ldots\ldots (2)$$

At this point it is well to fix the form of the functions *f* and φ. The former may be taken approximately as a power function of the diameter. If the pipe is effectively smooth, as many oil lines are, the approximation is very nearly exact. In this case:

$$f \propto R^{-n} \propto \left(\frac{4}{\pi} \frac{M}{\mu} \right)^{-n} \quad D^n$$

where: *n* is equal to *1* for the streamline region, $\frac{1}{4}$ for moderate Reynolds numbers in the turbulent range, and successively lower values for extremely high Reynolds numbers (see Fig. 3). In rough pipe the friction factor is a function of the relative degree and kind of roughness as well as the Reynolds number, but it still may be represented as a power function of the diameter with entirely adequate accuracy over a wide range of conditions. For example, Kemler's coefficients [3] for clean steel pipe in the range between *R*=25,000 and *R*=10,000,000 give *n*=0; i.e., they would indicate that, discharge being constant, the greater relative roughness of smaller steel pipe just offsets the effect of its higher Reynolds number. The same conclusion may be drawn from the old Fritzsche formula for gas (very good for small pipes under 6 in.) which gives *n*=0.03. Weymouth's gas formula would give $n = -\frac{1}{3}$; but this is a false value, for Weymouth developed his exponent from experiments when the flow rate increased with increasing diameter. Thus his exponent includes not merely the effect of diameter itself, but indirectly allows for the higher flow rate normally encountered in large pipe. Moreover, his exponent really is somewhat high.

To sum this up, it may be said that *f* is represented accurately enough as a power function of *D* with an index lying between 0 and +0.25 in the range of turbulent flow.

We have then:

$$f = \lambda D^n$$

where: λ is a factor of proportionality.

$$\frac{df}{dD} = n\lambda D^{n-1} = nfD^{-1}$$

Before this is inserted in equation (2), the value of $\phi(D)$ should be fixed. This also may be taken as a power function without significant error (see Fig. 4, which shows costs plotted on logarithmic coordinates). The index is about 1.25 for standard, light-weight, or extra-strong pipe; about 1.0 for insulated lines; and perhaps 1.75, or even more, for very thick high-pres-

[1] Centimeter-gram-second.

[2] This may be objected to on theoretical grounds, because continuous variation of *D* is not feasible in practice. The analysis can be made without this step. However, it is convenient, avoids unnecessary algebra, and gives the right answer; so it need not be apologized for further.

[3] Although the authors believe these coefficients too high for smooth steel pipe at moderate Reynolds numbers, nevertheless, they recommend the compilation as essentially sound.

sure lines whose thickness is determined by the use of a constant working stress.

Thus we have:

$$\phi(D) = \left(\frac{D}{D_0}\right)^{\gamma}$$

Inserting these values of $\phi(D)$ and $\frac{df}{dD}$ in equation (2) we get:

$$\frac{8}{\pi^2}(rk + ct)\,l\,\frac{M^2}{\rho^2}\,\frac{(n-5)f}{D^6} + rP_0 l\,\frac{\gamma}{D_0^{\gamma}}D^{\gamma-1} = 0 \quad \ldots\ldots\ldots (3)$$

Solving for D we get:

$$D = \left[\frac{8}{\pi^2}\,\frac{D_0^{\gamma}(5-n)}{\gamma}\,\frac{(rk+ct)f}{rP_0}\right]^{\frac{1}{5+\gamma}} \frac{M^{\frac{3}{5+\gamma}}}{\rho^{\frac{2}{5+\gamma}}} \quad \ldots\ldots (4)$$

Solving for M:

$$M = \left[\frac{\pi^2}{8}\,\frac{\gamma}{D_0^{\gamma}(5-n)}\,\frac{rP_0}{(rk+ct)f}\right]^{\frac{1}{3}} \rho^{\frac{2}{3}}\, D^{\frac{5+\gamma}{3}} \quad \ldots\ldots (5)$$

Solving for the mean velocity v, in terms of D:

$$v = \left[\frac{8}{\pi}\,\frac{\gamma}{D_0^{\gamma}(5-n)}\,\frac{rP_0}{(rk+ct)f}\right]^{\frac{1}{3}} \frac{D^{\frac{\gamma-1}{3}}}{\rho^{\frac{1}{3}}} \quad \ldots\ldots (6)$$

Solving for the mean velocity in terms of M:

$$v = \frac{4}{\pi}\left[\frac{\pi^2}{8}\,\frac{\gamma}{D_0^{\gamma}(5-n)}\,\frac{rP_0}{(rk+ct)f}\right]^{\frac{2}{5+\gamma}} \frac{M^{\frac{\gamma-1}{\gamma+5}}}{\rho^{\frac{\gamma+1}{\gamma+5}}} \quad \ldots\ldots (7)$$

These equations show that the economical mass-flow rate for any given diameter varies as:

1. The cube root of the ratio of the cost of pipe to the cost of power.

2. The ⅔ power of the density of the fluid. The volume rate then varies inversely as the cube root of the density. In the case of a perfect gas the economical volume rate, reduced to standard conditions, varies as the cube root of the absolute pressure [4] and inversely as the ⅔ power of the absolute temperature and the cube root of the specific gravity or molecular weight.

3. Inversely as the cube root of the friction factor, f. The effect of n, which is the index of the rate of change of f, is virtually insignificant in the turbulent-flow range. In fact, the extreme effect of this factor on the economic flow rate for a given diameter is not more than 2 percent or, say, 1 percent either way from a mean value. In other words, using the correct friction factor effectively takes care of all the hydraulics involved in the problem.

4. A power of the diameter somewhat greater than the square. The overall variation is a little faster than the exponent of D in the formula shows; because f is, in general, lower in the larger lines, both because of higher Reynolds number and greater relative smoothness. The rate, everything considered, ordinarily will vary about as the 2-1/6 power of the pipe diameter.

Before going into the practical use of these formulas, it will be advisable to transform them to commercial units of measurement.

The following conversion factors are wanted:

One horsepower	= 17,700 foot-poundals per second.
One horsepower hour	= 3,600 × 17,700 foot-poundals.
One year	= 8,766 hours.
One foot	= 12 inches.
One hour	= 3,600 seconds.

[4] This does *not* mean that the diameter of the pipe in a long gas line should be changed as the pressure declines—although under certain conditions it should be. This analysis applies *only* when the line is relatively short and the total change in density small. The analysis of the economics of long pipe lines is beyond the scope of this paper.

[*] This numerical factor changes but little with γ. Actual values:

γ	1.0	1.25	1.50	1.75	2.00
Factor	5.00	5.04	5.07	5.10	5.12

Let:

t′ = the load factor, or annual operating time, in years.
k′ = cost of machinery per hydraulic horsepower.
c′ = operating cost per horsepower hour.
D′ = diameter of pipe in inches.
M′ = rate of flow in *thousands* of pounds per hour.

Also, let us assume that $n = 0.1$ and that $D_0 = 0.5$ ft., or 6 in. Then equation (4) becomes:

$$D' = 12\left[\frac{(8)\,(0.5^{\gamma})\,(4.9)\,(3.6^3)}{\pi^2(17{,}700)}\right]^{\frac{1}{5+\gamma}}\left[\frac{(rk' + 8{,}766c't')f}{\gamma rP_6\rho^2}\right]^{\frac{1}{5+\gamma}} M'^{\frac{3}{5+\gamma}}$$

If γ in the index of the numerical factor be taken as 1.25 and the primes be dropped, this becomes:

$$D = {}^{*}5.04\left[\frac{(rk + 8{,}766ct)f}{\gamma rP_6\rho^2}\right]^{\frac{1}{5+\gamma}} M^{\frac{3}{5+\gamma}} \quad \ldots\ldots (8)$$

As this formula may be used in practical work to determine the economical diameter, it may be well to reiterate the dimensions and meaning of the letters:

D = most economical diameter of pipe, in inches.
r = annual rate of fixed charges, including all investment costs and desired minimum profit on money expended, considering risks involved, expressed as a decimal fraction.
k = cost of power machinery, dollars per fluid horsepower.
c = operating cost per horsepower of fluid friction.
t = load factor, or fraction of the year the plant operates.
f† = friction factor in the fundamental pipe-friction equation:

$$p' = f\rho\,\frac{1}{D}\,\frac{v^2}{2} \text{ (absolute units)}$$

γ = exponent in the empirical equation for the cost of pipe:

$$V_L = lP_0\left(\frac{D}{6}\right)^{\gamma}$$

P_6 = cost per foot of 6-in. pipe, installed under the conditions to be expected in the plant under consideration.
ρ = density of the fluid, under working conditions, in pounds per cubic foot.
M = mass rate of discharge in thousands of pounds an hour.

Although this formula is usable for solving individual problems, it is not so convenient for plotting a chart as one solved explicitly for M. By inserting conversion factors for commercial units in equation (5) one gets (omitting the primes):

$$M = \left[\frac{\pi^2(17{,}700)}{(8)\,(3.6^3)\,(12^5)\,(4.9)}\right]^{\frac{1}{3}}\left[\frac{\gamma rP_0\rho^2}{(rk + 8{,}766ct)f}\right]^{\frac{1}{3}} \frac{D^{\frac{5+\gamma}{3}}}{D_0^{\frac{\gamma}{3}}}$$

$$= 0.0727\left[\frac{\gamma rP_0\rho^2}{(rk + 8{,}766ct)f}\right]^{\frac{1}{3}} \frac{D^{\frac{5+\gamma}{3}}}{D_0^{\frac{\gamma}{3}}} \quad \ldots\ldots (9)$$

Obviously, if we let $D_0 = D$ (i.e., if for P_0 we insert P, the actual cost of pipe of diameter D) we get:

$$M = 0.0727\left[\frac{\gamma rP\rho^2}{(rk + 8{,}766ct)f}\right]^{\frac{1}{3}} D^{\frac{5}{3}} \quad \ldots\ldots (10)$$

Use of the Formulas

To use the formulas, or the charts plotted from them (Figures 1 and 2), it is necessary to know the cost of pipe, the cost of power, the fixed charges, and the friction factor, f.

† This factor is often denoted λ. Some writers use a factor ¼ or ⅛ as great numerically, and denote it by the same letter.

The cost of pipe is a mere matter of experience or estimating. As far as the formulas are concerned, any size may be selected as a standard of reference. Preferably, it should lie in the general vicinity of the size that will be used, in order to minimize any error due to variations in the index γ. If this precaution is taken, the index itself is not very critical.

The cost of power includes a term rk for fixed charges, and another ct for energy. The sum $rk+8{,}766\,ct$ is, of course, merely the total annual cost of one fluid horsepower of demand. Both terms are used to call attention to the fact that often the fixed charges are important. Also, when electric power is purchased, the schedules usually include a demand charge, which is the equivalent of the rk term, either directly or by the use of sliding rates—which, at least over a limited range,

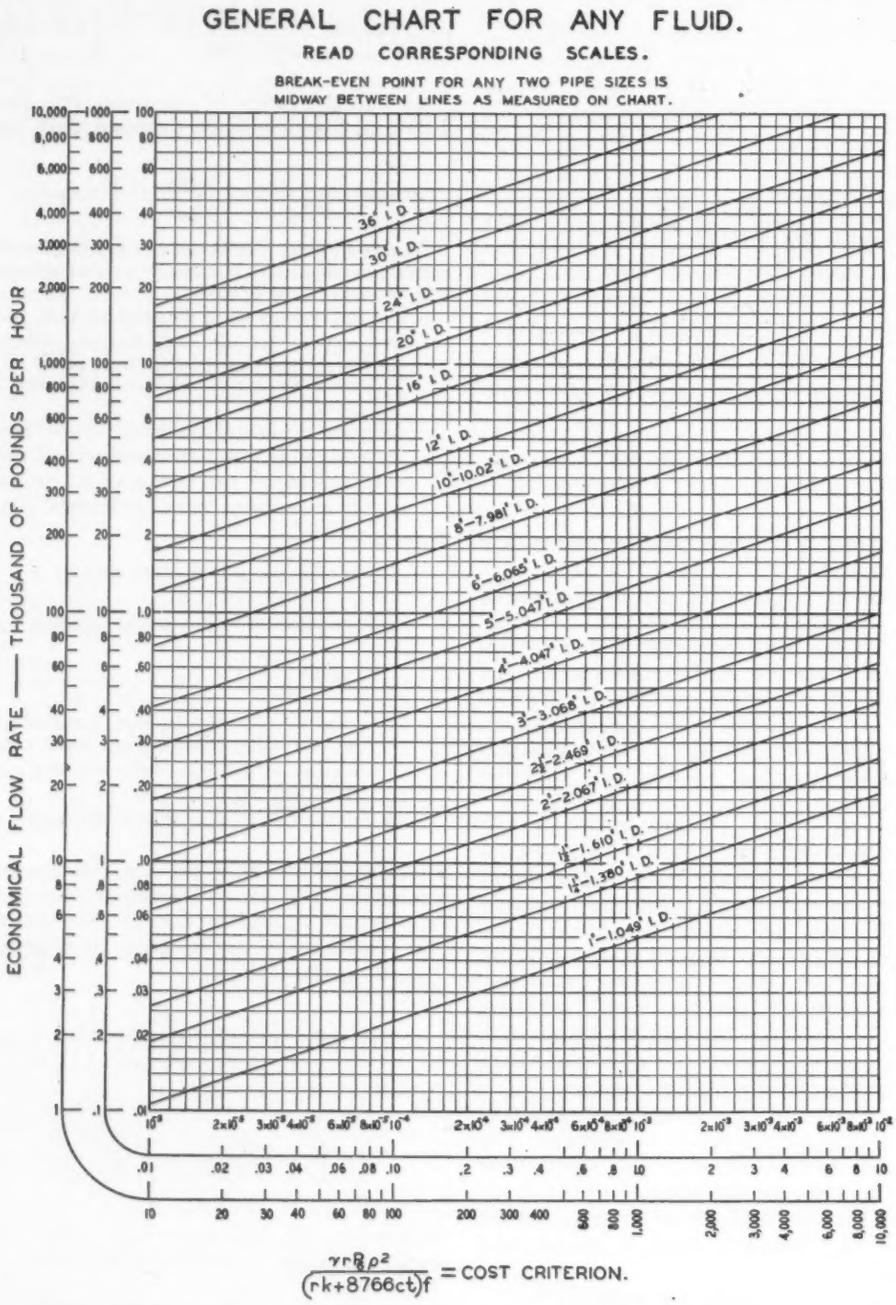

GENERAL CHART FOR ANY FLUID.
READ CORRESPONDING SCALES.
BREAK-EVEN POINT FOR ANY TWO PIPE SIZES IS MIDWAY BETWEEN LINES AS MEASURED ON CHART.
ECONOMICAL FLOW RATE — THOUSAND OF POUNDS PER HOUR
36" I.D.
30" I.D.
24" I.D.
20" I.D.
16" I.D.
12" I.D.
10"-10.02" I.D.
8"-7.981" I.D.
6"-6.065" I.D.
5"-5.047" I.D.
4"-4.047" I.D.
3"-3.068" I.D.
2½"-2.469" I.D.
2"-2.067" I.D.
1½"-1.610" I.D.
1¼"-1.380" I.D.
1"-1.049" I.D.
$\frac{\gamma r P_6 \rho^2}{(rk+8766ct)f}$ = COST CRITERION.
r = RATE OF FIXED CHARGES, EXPRESSED AS A FRACTION OF THE FIRST COST.
P_6 = FIRST COST OF 6" PIPE PER FOOT OF LENGTH.
k = COST OF MACHINERY PER FLUID HORSEPOWER.
C = COST OF OPERATING MACHINERY, DOLLARS PER FLUID HORSEPOWER—HOUR.
ρ = DENSITY OF FLUID, POUNDS PER CUBIC FOOT.
t = FRACTION OF TIME THAT PUMPING MACHINERY OPERATES, OR LOAD FACTOR.
f = FRICTION FACTOR FOR PIPE.
D = INSIDE DIAMETER, INCHES.
γ = EXPONENT IN PIPE COST FORMULA WHERE PIPE COST PER FOOT = $P_6\left(\frac{D}{6}\right)^{\gamma}$. (γ IS GENERALLY CLOSE TO 1.25).
NOTE : CHART IS THEORETICALLY EXACT FOR γ = 1.25 AND GIVES REASONABLY ACCURATE RESULTS FOR OTHER VALUES OF γ.

FIGURE 1
Economic Flow Rate for Pipe Lines

are reducible to the same thing. When a plant generates its own power, a question always comes up regarding the proper charge, and particularly the amount of plant capacity actually used up by any given increment of load. Unless the load factor is 100 percent or the load in question represents a large fraction of the installed capacity, there will be a diversity factor less than unity which should be applied to any given load increment to find its effect on the power plant. When a load is in fact scheduleable to off-peak hours, the diversity factor even may be zero. A sound estimate of diversity requires a real knowledge of everything connected to the power system, although a reasonable guess somewhere between 50 and 100 percent is often all that is either justified

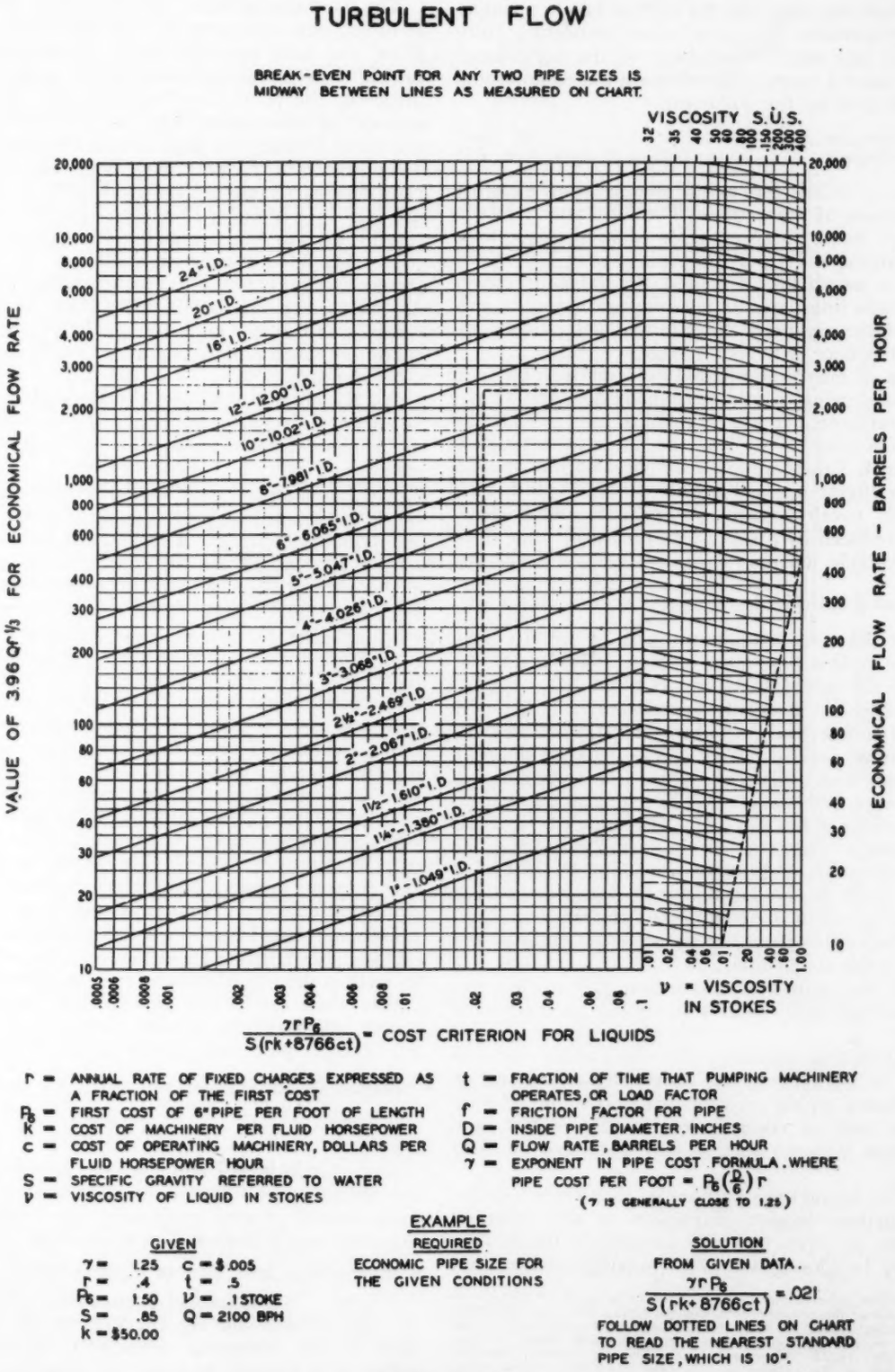

TURBULENT FLOW
BREAK-EVEN POINT FOR ANY TWO PIPE SIZES IS MIDWAY BETWEEN LINES AS MEASURED ON CHART.
VISCOSITY S.U.S.
VALUE OF 3.96 Qγ^1/3 FOR ECONOMICAL FLOW RATE
ECONOMICAL FLOW RATE - BARRELS PER HOUR
24"-I.D.
20"-I.D.
16"-I.D.
12"-12.00"I.D.
10"-10.02"I.D.
8"-7.981"I.D.
6"-6.065"I.D.
5"-5.047"I.D.
4"-4.026"I.D.
3"-3.068"I.D.
2½"-2.469"I.D.
2"-2.067"I.D.
1½"-1.610"I.D.
1¼"-1.380"I.D.
1"-1.049"I.D.
ν = VISCOSITY IN STOKES
γrP6 / S(rk+8766ct) = COST CRITERION FOR LIQUIDS
r = ANNUAL RATE OF FIXED CHARGES EXPRESSED AS A FRACTION OF THE FIRST COST
P6 = FIRST COST OF 6" PIPE PER FOOT OF LENGTH
k = COST OF MACHINERY PER FLUID HORSEPOWER
c = COST OF OPERATING MACHINERY, DOLLARS PER FLUID HORSEPOWER HOUR
S = SPECIFIC GRAVITY REFERRED TO WATER
ν = VISCOSITY OF LIQUID IN STOKES
t = FRACTION OF TIME THAT PUMPING MACHINERY OPERATES, OR LOAD FACTOR
f = FRICTION FACTOR FOR PIPE
D = INSIDE PIPE DIAMETER. INCHES
Q = FLOW RATE, BARRELS PER HOUR
γ = EXPONENT IN PIPE COST FORMULA. WHERE PIPE COST PER FOOT = P6(D/6)^γ
(γ IS GENERALLY CLOSE TO 1.25)
EXAMPLE
GIVEN
γ = 1.25 c = $.005
r = .4 t = .5
P6 = 1.50 ν = .1 STOKE
S = .85 Q = 2100 BPH
k = $50.00
REQUIRED
ECONOMIC PIPE SIZE FOR THE GIVEN CONDITIONS
SOLUTION
FROM GIVEN DATA.
γrP6 / S(rk+8766ct) = .021
FOLLOW DOTTED LINES ON CHART TO READ THE NEAREST STANDARD PIPE SIZE, WHICH IS 10".

FIGURE 2
Economic Flow Rate for Liquids

or possible. The authors can offer but little advice, except the suggestion that extreme assumptions or the commoner forms of false reasoning be avoided.

Attention is called also to the fact that the formulas refer to *fluid power*, not power at the engine shaft or electric feeder. The factor between the two may be definite, easy to understand, and well-known, as in the case of a motor-driven centrifugal pump, or perhaps relatively unobvious, but it always can be found. As a simple example one may take the suction line to a single-stage gas compressor. Here the factor connecting fluid-power losses and shaft horsepower of the compressor varies over quite a range, depending on the compression ratio as indicated by the following:

Ratio of compression.....	1.5	2.0	3.0	4.0	6.0
Incremental efficiency.....	0.75	0.70	0.64	0.60	0.55

Attention is called also to the necessity of allowing for the direction of power flow. The fluid power lost in the discharge line of a compressor is worth more than the power at the shaft, but the fluid power lost in the steam line is worth less. Further, the value of power loss in a steam line depends not only on the cycle and efficiency of the engine or turbine that uses the steam, but on what is done with the exhaust.

The value of energy dissipated by frictional losses in a steam line serving power equipment depends on the expansion ratio or temperature limits over which the equipment operates, as well as the ultimate disposition of the exhaust. Take a simple example of a line serving steam to an engine operating with variable cutoff, or a turbine with nozzle control. When the initial steam pressure is reduced by a small increment, the immediate loss of available energy is given correctly by the $\frac{M}{\rho} p'$ term used in deriving the pipe-size formulas. However, it is well-known that the ultimate effect on engine performance is less than this, because some of the reheat due to the initial throttling is ultimately recoverable. The ratio of the finally unrecoverable loss to the initial loss is numerically equal to the ratio of the slope of the constant pressure lines on the Mollier diagram at the exhaust and initial conditions. For an engine operating between 140 pounds absolute and 1 pound absolute, the ratio is about 0.70. If the engine efficiency is 0.45, the value of frictional energy loss in the steam line is $0.70 \times 0.45 = 0.32$ as great as the value of energy at the engine shaft. If the engine drives a gas compressor, the value of losses in the compressor suction line might in turn be twice this great, or six times as great as the same loss in the steam line.

Evidently the reheat or expansion factor just discussed would not apply to losses between an engine and a condenser.

It is evident that the effect described is the same as that noted in the table given previously in connection with compressor piping—except that in case of the compressor the heat of compression usually is lost, and the distinction between suction and discharge line disappears.

It would be beyond the purpose of this paper to enter into any further detailed discussion of the value of power losses in pipes carrying expansible fluids. The subject may be closed with the probably unnecessary observation that power losses in piping do not necessarily have any value at all. If all the energy available in a fluid inevitably is to be lost anyway, it is more economical to lose part of it in the piping than all of it in a throttle valve. Sometimes, on the other hand, need for constant system pressure may demand piping much larger than power economy would warrant, as it did in the obsolescent low-pressure gas-distributing systems in cities.

The fixed-charge rate r should include all capital costs including due allowance for obsolescence, maintenance, risks, and such taxes as apply. Obviously, one of the capital costs is the minimum profit or interest that the owner of the plant is willing to accept on an added increment of investment. The same symbol r is used for the fixed charges on pipe as for the fixed charges on power machinery. This does not mean that the same rate necessarily should be used in both places. Either one may be higher, or they may be equal—depending on conditions. On the one hand, the piping in a process plant may have a very high rate of obsolescence or a short expected physical life; whereas the power-generating machinery may serve other loads also, and have a low obsolescence. On the other hand, there may be a condition when engine depreciation is high and pipe costs are low.

All the economic factors can be, and should be, fixed before any design work starts. From then on the use of the charts and formulas becomes largely a mechanical process.

The remaining factor, and the only one except the fluid density that has anything to do with hydraulics, is the friction factor, f. The significance of this factor, and at least a rough idea of its probable value in common cases, is usually at the command of anyone who has done much piping design. This however, does not alter the fact that an accurate estimate of the friction factor in any given case ordinarily requires a knowledge of at least two of these factors in addition to the properties of the fluid: rate of flow, pipe diameter and pressure drop (see Figure 3).[5] Presumably only the rate of flow is known. Thus a trial-and-error procedure is indicated. A trial value—say 0.02, or almost any value within reason—of f is taken, and the economic diameter is found. Then the Reynolds number may be calculated, and the corresponding friction factor for the conditions may be determined. With this factor, the original selection may be verified. It may not be amiss to point out that the effective friction factor may be increased greatly on short lines by a large number of elbows, tees, or other obstructions; and that it is the effective factor, as well as the effective average cost, that should be used rather than the factor for straight pipe. If l is the length of line, f_e the effective factor, f the actual factor for straight pipe, and ζ the ratio of the loss in the obstruction to the velocity pressure, $\frac{\rho v^2}{2}$, then:

$$f_e = f + \frac{\zeta D}{12\, l}$$

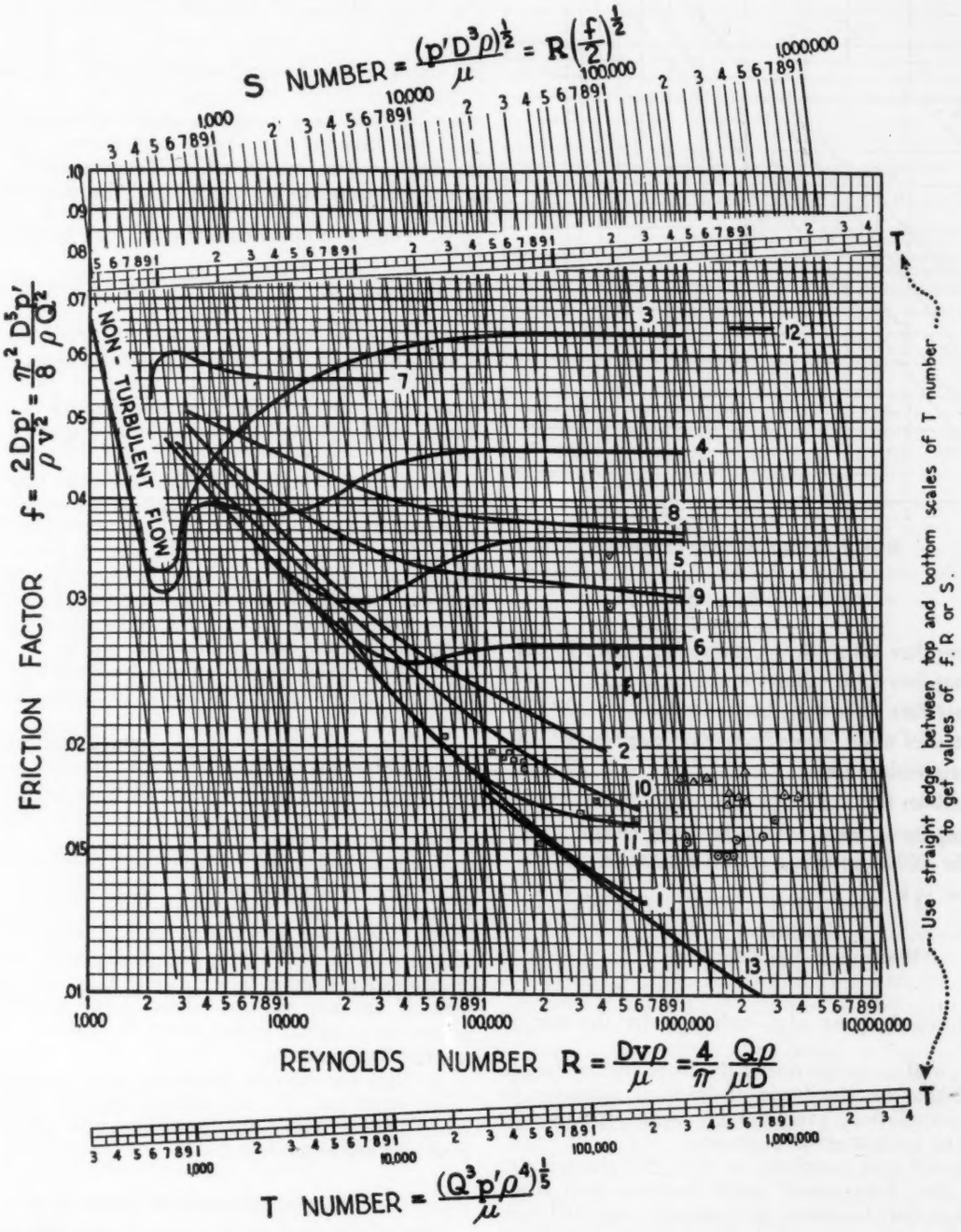
when: D is in inches and l in feet. It is very common to find the effective f double the f for straight pipe in short lines around process equipment, particularly if care is not exercised to keep the design as clean as possible.

Construction and Use of Charts (Figures 1 and 2)

Figure 1 is a graphical presentation of equation (9). Its construction and use are both rather evident, in the light of the foregoing discussion. By using multiple scales, it is possible to cover an unlimited range of the economic factors. The three scales shown will cover almost any usual problem, but they easily can be ex-

[5] Figure 3, which permits the friction factor to be read off directly in terms of *any pair* of the possibly unknown quantities, flow rate, diameter, and pressure drop, instead of being limited to a single pair such as the one contained in the Reynolds number, is reproduced from a paper presented to the ASME Aeronautics-Hydraulics meeting at Stanford University by one of the authors in 1934 (see *Mechanical Engineering*, Dec. 1937, p. 960). It is not realized commonly that what is designated as the S number on this chart was invented by Osborne Reynolds himself. The S and T numbers, although often very useful, are not directly used in the problem now under consideration.

tended further if required. After the cost criterion has been established, the chart shows the mass-flow rate for which each size of pipe is most economical. The chart is plotted on the basis of $\gamma=1.25$. However, it will be exactly correct for 6-inch pipe (which is taken as the standard of reference) irrespective of the value of γ. For other sizes there will be an error in the flow rate, but it will be entirely negligible in most cases. For an extreme value of $\gamma=1.75$, which would be reached only with very thick high-pressure lines, the error would be 10 percent with 12-inch pipe. Practically, a 10-percent error in the economical flow rate would have little significance. Even this error can be avoided by increasing P_6 in the ratio of the actual cost of the pipe to that



LEGEND

1. Stanton and Pannell, smooth brass pipe
2. Lander, 1/2" to 1-1/2" clean steel pipe
3. Nikuradse, Pipe artificially roughened by coating inside with graded sand. Ratio of radius to grain size-15
4. " " " " " " 30
5. " " " " " " 60
6. " " " " " " 126
7. Beale and Docksey, 1/4" Galvanized pipe
8. Beale and Docksey, 1/2" Galvanized pipe
9. Gibson, 2" Galvanized pipe
10. Swindin 2" to 5" pipe
11. Anglo-Persian Oil Co. Natural Gas Pipe Lines 8"-12". Approximate, increases with age.
12. Submarine loading hose, inside wire reinforcement.
13. Nikuradse, Turbulent flow in smooth tubes, 1/4" to 2-1/2" dia. Approximates Stanton and Pannell for values of R below 100,000.

△ -16" Estero loading line.
⊙ -20" Estero loading line.
⊡ -10" Kettleman Estero line.
▽ -Before scraping ▼ -After scraping } El Segundo-San Pedro 8" Gasoline Line

FIGURE 3
Friction Factors

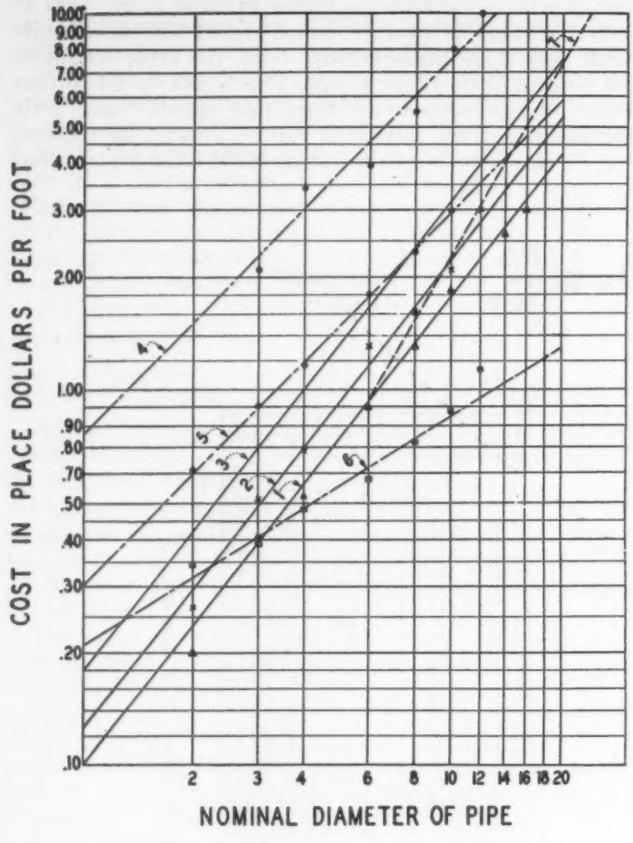


FIGURE 4
Illustrative Pipe-Cost Data

calculated from the cost of 6-inch pipe by the use of $\gamma=1.25$.

It may be well to mention that the lines for the larger sizes are plotted on the basis of internal diameter to facilitate interpolation, even though large pipe usually is not made to even internal diameters.

Another point that comes up in using the chart is the location of the "break-even" point between two sizes. One does not wish to know, for example, that 6.9-inch pipe would be most economical; what one does want to know is whether to use 6-inch or 8-inch. The flow at which any two sizes are equally economical, or the break-even point, is approximately the geometric mean of the flows for which each is most economical. As the chart is drawn to a logarithmic scale, the break-even curve between any two sizes is, for practical purposes, halfway between them on the chart.

Although the chart shown in Figure 1 is general and not really at all difficult to use, it is possible to make charts that avoid the necessity of a knowledge of the friction factor, f. One of these, which applies to liquids only, is shown in Figure 2. This chart is plotted from equation (9) by replacing the mass-flow rate M by the volume rate $Q=\frac{M}{\rho}$, and then bringing $f^{\frac{1}{3}}$ to the left of the equation, obtaining the equation:

$$\frac{Q}{f^{\frac{1}{3}}}=0.0727\left[\frac{\gamma r P_o}{(rk+8{,}766ct)\rho f}\right]^{\frac{1}{3}}\frac{D^{\frac{5+y}{3}}}{D_o^{\frac{y}{3}}} \quad \ldots\ldots (11)$$

If this chart is entered at the bottom, the ordinate $\frac{Q}{f^{\frac{1}{3}}}$ may be read as a function of D. When the factor D, and the kinematic viscosity are known, there is only a single value of Q which is compatible with any given relationship between f and the Reynolds number $\frac{4Q}{\pi vD}$. Thus a supplementary chart can be plotted giving Q in terms of $\frac{Q}{f^{\frac{1}{3}}}$ and v. Naturally it will apply only to a particular kind of pipe and, theoretically, only to a single diameter. In practice, however, large Q's always go with large pipe, and the value of $f^{\frac{1}{3}}$ changes but slowly; therefore, a single supplementary chart, such as that actually plotted on the right of Figure 2, does well enough.

This correction chart is not based on any particular set of published coefficients but, rather, on the authors' general experience, which can be summed up thus:

1. The smooth-pipe law will hold in clean black steel pipe 6 in. and larger, provided the Reynolds number does not exceed 80,000; provided the pipe was commercially clean to start with; and provided the fluid does not corrode nor rust the pipe nor leave deposits.
2. The friction in sizes under 6 inches will be greater than the smooth-pipe law would indicate, depending on size.
3. The very low friction factors indicated by the smooth-pipe law at high Reynolds numbers are not commercially obtainable in the usual lines carrying liquids, and it is good judgment to set a lower limit of 0.016 for the friction factor.

The data in Figure 3 verify these conclusions.

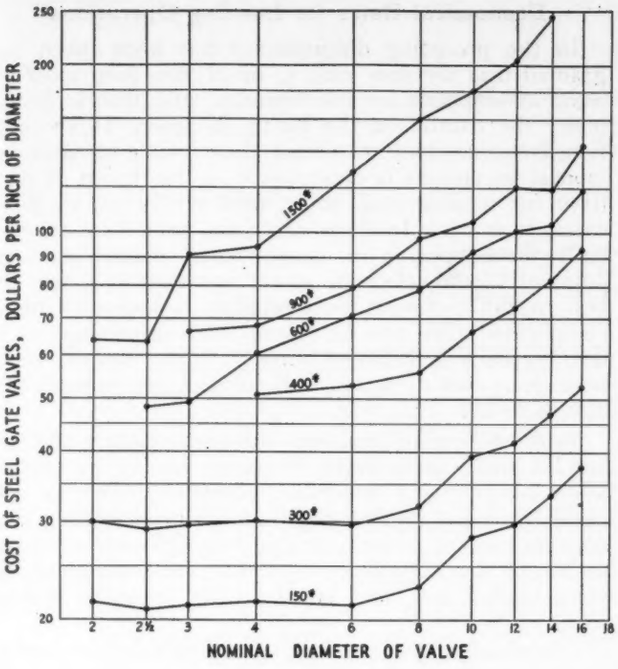
The advantage of working with Figure 2 rather than Figure 1 is that it permits a solution to be read off by anyone, whether familiar with hydraulics or not, and that it gives results in the commonly used volume units. The disadvantage is lack of generality, and particularly lack of an easy way to adjust f for incidental resistances. In practice, either chart is probably as accurate as the data warrant.

A chart for viscous streamline flow has been made up from equation (4) by substituting the proper values for f and n, but it has shown so little practical utility that it is not reproduced.

Determination of Valve Size

One of the most costly parts of a piping system often is the valves. This is especially true in high-pressure or high-temperature work where ASA series steel valves are used. In such cases a considerable saving often can be made by installing gate valves one or two sizes smaller than the pipe line. By the use of the pipe-cost equations previously given, it is possible to reduce this practice to a systematic and rational basis.

Attention is called to Figure 5, which shows the approximate ratio of steel-valve cost to the nominal diameter in inches. Figure 5 is included for illustration rather



NOTE: Cost data are for illustrative purposes only

FIGURE 5
Approximate Cost of Steel Gate Valves

than for use as an actual estimating price sheet. Of course, prices and discounts vary. This figure does not include the flanges and bolts nor the installation; for at least a part of the savings that can be made in these items will be offset by the cost of swages and tapers required if less than full-size valves are used. The values in Figure 5 indicate that, whatever reason there may be for the trend of costs, the rhyme is not such as to inspire an attempt to reduce the schedule to any algebraic law.

The procedure, therefore, will be to evaluate the extra cost of hydraulic losses in small valves in terms of the cost of straight pipe, and to compare this with the indicated saving in valve cost from the price schedule. The fundamental assumption made is that the pipe in which the valve is placed is sized correctly. With this assumption, all factors such as fixed charges, load factor, power costs, etc., disappear, and the problem becomes a simple balance between valve cost and pipe cost.

In order to calculate the loss through reduced-size valves of any type, let:

η = coefficient of loss of valve and taper, referred to pipe diameter.
ζ = ratio of loss through valve itself to the velocity pressure, referred to valve diameter.
ξ = coefficient in Borda's formula, which depends on the divergence angle of the taper, varying from 0.13 to 1.2.
m = ratio of valve diameter to pipe diameter.

Then:

$$\eta = \frac{\zeta}{m^4} + \xi\left(\frac{1}{m^2} - 1\right)^2$$

Values of η for gate valves with $\zeta = 0.2$ are shown in Fig. 6. Then the pressure loss through the valve is:

$$p' = \eta \frac{8}{\pi^2} \frac{M^2}{\rho D^4} \text{ (absolute units)}$$

and the cost of power loss is:

$$V_E = (rk + ct)\eta \frac{8}{\pi^2} \frac{M^3}{\rho^2 D^4}$$

If this is combined with equation (3) from the foregoing study on pipe size, and if $D_0 = D$ and $P_0 = P$, the following relationship is secured:

$$V_E = \frac{\eta}{f} \frac{rP\gamma D}{5 - n}$$

However, if we capitalize the annual power cost at the rate r, insert a mean value of 0.1 for n, and convert D to inches, we get:

$$V_c = \frac{\gamma}{58.7} \frac{\eta}{f} PD$$

Where:

V_c = capitalized present worth of all the loss through the valve, in dollars.
γ = index of pipe cost—say 1.25.
η = coefficient of valve loss.
f = friction factor in straight pipe.
P = cost of pipe, dollars per foot.
D = diameter of pipe in inches.

The same relationship can be secured by a direct course of reasoning, in which power cost is not mentioned at all; hence, it is general and applies to all lines.

The *extra* power cost, due to using a valve with a loss of η_2 instead of a loss η_1 is evidently:

$$\frac{\gamma PD}{58.7f}(\eta_2 - \eta_1)$$

If this is less than the amount to be saved by using a valve of smaller size, then the smaller valve is economical; otherwise it is not.

As an example, consider that we wish to put steel valves in a 10-inch pipe line which costs $2.50 a foot, and operates with $f = 0.018$. Consider: *a*, 900 series valves; and, *b*, 150 series. Assume that 12-degree tapers will be used, and take η from Figure 6:

Proposed size of valve	10 in.	8 in.	6 in.	5 in.	4 in.
m	1	0.8	0.6	0.5	0.4
n (with 12-deg. tapers)	0.2	0.55	2.18	5	13.1
$n_2 - n_1$	....	0.35	1.63	2.82	8.1
$\frac{\gamma PD}{58.7f}(n_2 - n_1)$	....	$ 10	$ 48	$ 84	$240
Incremental saving, 900 series	....	$268	$305	$103	$103
Incremental saving, 150 series	....	$ 97	$ 57	$ 20	$ 21

Thus it appears that a 5-inch valve is most economical for the 900 series, and a 6-inch valve for the 150 series. By using a 5-inch valve of the 900 series a *net* capital saving of $268 + 305 + 103 — (10 + 48 + 84) or $534 is effected. If there were a cheap 125-pound cast-iron valve involved, it might be best to install it full-size.

Attention is called to the importance of having a smooth gradual taper on the downstream side of any valve smaller than the pipe line, particularly if more than one size smaller. The curves in Figure 6 were calculated from data in Gibson's *Hydraulics*, which gives ξ as a function of the angle of taper. The common swaged nipple stocked by most manufacturers and jobbers, when used as an increaser, is about as poor a fitting from the standpoint of the user's pocketbook as one possibly could design. It is all right for a reducer, but not appreciably better than a gradual taper. The difficulty of stocking and choosing between two types of reducer is a strong argument for abandoning the conventional style entirely. Gradual tapers are available when insisted on, and would be stocked generally if the users demanded them. They should be standardized on the basis of a total taper of 1:5. A swage with a total diverging angle of 40 degrees is as bad as a sudden square-cornered enlargement; and one with a 60-degree angle, which some swages actually have, is 20 percent worse. One should remember also that if no expander is used, as for example if the outlet of the small valve is allowed to discharge into a

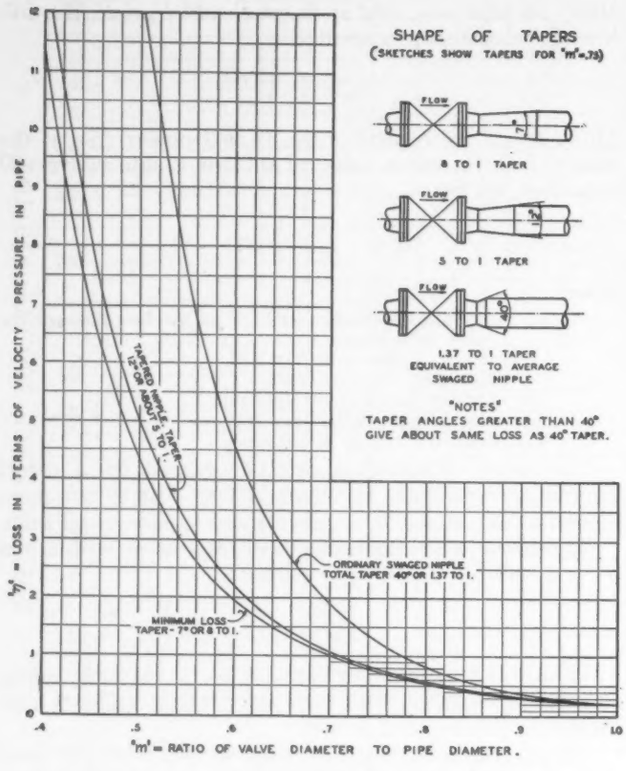

SHAPE OF TAPERS
(SKETCHES SHOW TAPERS FOR m²=.75)
FLOW
8 TO 1 TAPER
FLOW
5 TO 1 TAPER
FLOW
1.37 TO 1 TAPER
EQUIVALENT TO AVERAGE
SWAGED NIPPLE
"NOTES"
TAPER ANGLES GREATER THAN 40°
GIVE ABOUT SAME LOSS AS 40° TAPER.
TAPERED NIPPLE 12" OR MORE 5 TO 1 TAPER
ORDINARY SWAGED NIPPLE
TOTAL TAPER 40° OR 1.37 TO 1.
MINIMUM LOSS—
TAPER - 7° OR 8 TO 1.
η = LOSS IN TERMS OF VELOCITY PRESSURE IN PIPE
m² = RATIO OF VALVE DIAMETER TO PIPE DIAMETER.

FIGURE 6
Loss in Gate Valves Smaller Than the Pipe

tee, the value of η will be much greater than the curve sheet shows. Space limitations sometimes make proper installation of small valves a problem; but, as a rule, a little imagination and effort, backed by an appreciation of the economic factors involved, will overcome the difficulties.

Needless to say, globe and angle valves which have a ζ value of 5 to 10 (i.e., an η of 5 to 10 when full-size) are not to be economically reduced in size—or used at all if they can be avoided. Certain types of plug cocks have a ζ of about 2. They cannot be reduced much. If gate-valve manufacturers were willing to spend a bit more effort to clean up the inside of their valves, better results than those shown could be secured.

The treatment just given for valves obviously applies to all features of piping design which add incidental resistance. Thus, for example, suppose one wishes to decide whether to use a 3-piece mitered elbow or a drawn-steel welding fitting for a 90-degree turn. Knowing the value of η for both fittings and the cost of straight pipe, one may determine at once the extra value of the more expensive fitting. If the extra installed cost of it is less, it is a good investment; otherwise not (as a rule). For example, say $D = 12$ inches, η for the 3-piece miter is 0.50, and for the welding elbow, 0.30, while the cost per foot of straight pipe is $3.50. Then the extra value of the welding elbow is, say:

$$\frac{(1.25)\ (3.50)\ (12)}{(58.7)\ (0.016)}\ (0.50 - 0.30) = \$11.20$$

and this is all the welding elbow is worth over the miter, unless it is required for its somewhat greater strength. Of course, there are instances when the piping, for one reason or another, is necessarily too small for best economy. In such cases this analysis would not apply without some adjustment.

Economical Rates for Loading Operations

In the preceding discussion it has been taken for granted that the flow rate, Q or M, has been fixed by basic assumptions or requirements, and that it is not under the control of the piping designer. This condition, however, does not obtain always. One of the commonest exceptions is encountered in the design of pipe lines for loading tank ships, tank trucks or, in some cases, tank cars. In these cases the annual or *average* daily throughput is the fundamental datum, and the designer should select the actual flow rate to secure the best overall economy. This problem is somewhat more complicated than the foregoing ones—involving, as it does, a balance between three factors: cost of pipe, hose, etc.; cost of power and pumping equipment; and cost of delay.

In the following treatment the nomenclature and examples apply particularly to marine loading terminals. With scarcely any important alteration, however, the same treatment applies to the design of unloading systems on tankers (where the shore facilities are adequate to accept the high flow rates that are economical on short hauls) and, on a smaller scale, to truck loading racks.

The attack on this problem will be different from that in the preceding discussion. A formula and chart will be developed for determining the most economical flow rate for a system of assumed frictional resistance. The selection of the system having the most economical resistance then will be left to a tabular comparison. No doubt the final tabular comparison could be eliminated by further algebra if the loading line consisted merely of a single steel pipe of uniform cost. There are, however, as a rule many other factors which determine the system resistance, such as ship's piping, hose, submarine pipe line, etc.—each of which involves a different cost factor, and some of which may not be under the control of the designer. Then, too, circulating lines may be involved. These factors are so numerous, and vary so much from case to case, that an attempt to cover them all in an analytical treatment seems unwarranted. The principles used previously in the treatment of gate valves can be applied in determining what size the hose should be in comparison to the pipe line, what ratio the size of the circulating line should bear to the main line (it should be as small as its duties permit), etc.; but the following development assumes that the system resistance is known. It also assumes that gravity head is negligible. When it is not, the required alterations are left to the reader.

The nomenclature will be as before, except that commercial units of measure will be used throughout. The following additional symbols are used:

Value of boat's time[6] (including value of wharfage time, etc.) dollars per hour ..... B
Cost of entire loading system, except pumping machinery .. L
Economical loading rate, thousands of barrels per hour .... Q
Average daily throughput, barrels ..... A
Pressure drop through loading system at a rate of 5000 bbl. per hour ..... H_5

(The drop at 5000 barrels per hour is selected because it lies in the range of economical rates, and so minimizes any possible error due to departure of the pressure drop from the law assumed.)

[6] Strictly speaking, this should contain sometimes an extra allowance for delay of ship's awaiting berthing space. The analysis of this problem involves the use of the theory of probability, and is beyond the scope of this paper. It may be said, however, that if this extra delay is serious, the most effective remedy usually is more berths rather than faster loading in existing berths.

The annual cost of ship's time will be:

$$0.365\,\frac{BA}{Q}$$

The pressure drop is proportional to a power of the flow rate between the $\frac{7}{4}$ power and the square—say, on the average, the 1.85 power. Then the pressure drop is:

$$H_s\left(\frac{Q}{5}\right)^{1.85}$$

The hydraulic horsepower is:

$$E = 0.0208\,H_s Q^{2.85}$$

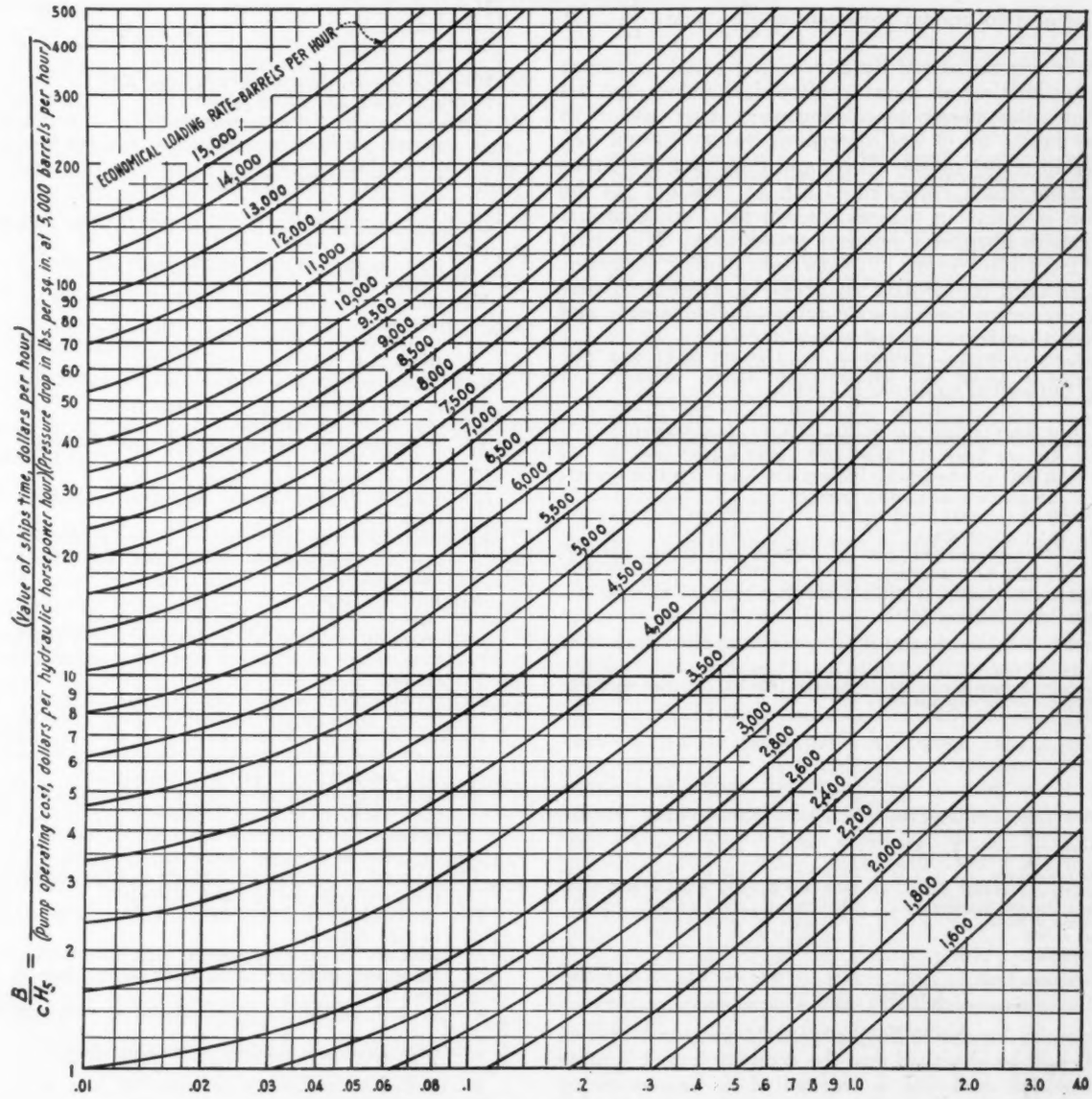
And the annual cost of the pumping plant is:

$$V_E = kEr + 0.365\,\frac{cEA}{Q}, \text{ or}$$

$$= 0.0208\,kr\,H_s Q^{2.85} + 0.0076\,cAH_s Q^{1.85}$$

The total annual cost, including ship's time and pumping plant is:

Curves give the economical loading rate for a given loading line; – that is for a line with a given friction drop at 5000 B.P.H. The economical pipe size is the one that gives lowest total annual costs at its economical loading rate.



$$\frac{kr}{cA} = \frac{\text{(First cost of pumping machinery, dollars per hydraulic horsepower)(Fixed charges on pumping machinery)}}{\text{(Pump operating cost, dollars per hydraulic horsepower hour)(Average daily throughput, barrels)}}$$

EQUATION: At economical loading rate, $\left(\frac{B}{cH_s}\right) = .162\left(\frac{kr}{cA}\right)Q^{3.85} + .0386Q^{2.85}$

Where Q = economical loading rate in thousands of barrels per hour, and other symbols are as shown on curve scales.

EXAMPLE: B = \$47 per hyd. h.p.; r = .20; c = \$.0041 per hyd. h.p. hour;
A = 20,000 B.P.D.; B = \$35 per hour; H_s = 190 lbs. per sq. in. at 5000 B.P.H.

From which $\frac{kr}{cA}$ = .115 and $\frac{B}{cH_s}$ = 45. From curves, economical loading rate = 7100 B.P.H.

FIGURE 7
Economical Loading Rates for Marine Terminals

$$V = 0.365\frac{BA}{Q} + 0.0208\,kr\,H_s Q^{1.85} + 0.0076\,cAH_s Q^{1.85}$$

Differentiating with respect to Q and equating to zero to find the value of Q corresponding to a minimum V, we get:

$$-0.365\frac{BA}{Q^2} + 0.0593\,kr\,H_s Q^{1.85} + 0.0141\,cAH_s Q^{0.85} = 0$$

which may be rearranged thus:

$$\frac{B}{cH_s} = 0.162\left(\frac{kr}{cA}\right)Q^{2.85} + 0.0386\,Q^{2.85}$$

This equation cannot be solved explicitly for Q by algebra alone. Nevertheless, it establishes Q as a definite function of two known parameters, $\frac{B}{cH_s}$ and $\frac{kr}{cA}$. Of course, it can be solved by any of the usual processes of approximation as soon as numerical values are assigned to the parameters. However, it is easier to assume values of Q and determine values of one parameter in terms of the other, and then plot a contour chart from which values of Q can be read off. As the equation is linear in the two parameters, the contours are straight lines in Cartesian coordinates. The chart is reproduced in Figure 7. It has been plotted, however, in logarithmic coordinates to preserve a uniform percentage accuracy over a wide range of flow rates; and the lines, therefore, are not straight.

In order to illustrate the method to be used, the following numerical example is given.

Let:

A = 20,000 bbl. per day (average daily throughput).
B = $35 per hour (value of ship's port delay).
c = $0.0041 per hydraulic horsepower hour (cost of operating engines on loading pumps).
r = $0.20 (annual fixed charges on investment, including return on capital).
k = $47 (incremental cost of engines and pumps per hydraulic horsepower).
H_s, values as shown in table (pumping pressure at 5000 bbl. per hour loading rate).

Size of main pipe line	14 in.	16 in.	18 in.	20 in.
Cost of variable portion of pipe line	$54,000	$69,700	$87,100	$106,300
H_s (including 25 lb. for hose and ship's piping)	135	83.5	58	46
$\frac{kR}{cA}$	0.115	0.115	0.115	0.115
$\frac{B}{cH_s}$	63.2	102	147	186
Q, read from figure, barrels per hour	7,800	8,900	9,800	10,500
Pressure drop $=\left(\frac{Q}{5{,}000}\right)^{1.85}\times H_s$	307	242	202	181
Hydraulic horsepower	980	880	810	775
Cost of machinery at $47	$46,000	$41,500	$38,100	$36,400
Cost of pipe line and machinery	100,000	111,200	125,300	142,700
Fixed charges at $0.20	20,000	22,240	25,060	29,500
Ship delay at $35	32,800	28,700	26,100	24,300
Engine operation	3,750	2,980	2,500	2,200
Total annual cost	$56,550	$53,920	$53,660	$56,000

Evidently the choice lies between 16-inch and 18-inch pipe. It will be observed that the economy curve is quite flat, provided each line is worked at its best economy point. Thus if the throughput is apt to increase, it may be good judgment to lean toward the larger pipes and provide for increased pumping power later on when the throughput increases.

Acknowledgment

In closing, the authors wish to thank their colleague, M. Ludwig, for his assistance.

Nomenclature

A = average daily throughput of a marine or other loading terminal, barrels.
B = value of boat's time, dollars per hour.
D = inside diameter of pipe, absolute units or inches, as indicated.
D_0 = inside diameter of reference pipe (usually 6 in.).
E = fluid power dissipated by pressure loss.
H_s = pressure drop, in pounds per square inch, through a marine loading system at a rate of 5000 bbl. per hour.
M = mass-flow rate, absolute units or pounds per hour, as indicated.
P = cost of pipe per unit length, absolute units or dollars per foot, as indicated.
P_0 = cost per unit length of reference pipe.
P_6 = cost per foot of 6-in. pipe.
Q = volume rate of flow, usually barrels or thousands of barrels per hour as stated [cubic feet per hour in equation (11)].
R = Reynolds number, dimensionless.
$S = \text{dimensionless flow criterion} = R\left(\frac{f}{2}\right)^{\frac{1}{2}}$ in Figure 3; also specific gravity of a liquid referred to water, Figure 2.
T = dimensionless flow criterion (see Figure 3).
V = total annual cost.
V_E = annual cost of power loss resulting from pressure loss through a valve or section of pipe.
V_c = capitalized present worth of all the power loss through a valve, dollars.
V_L = annual cost of pipe line.
c = incremental operating cost per unit of energy, absolute units or dollars per horsepower hour, as indicated.
f = friction factor, dimensionless.
f_e = effective friction factor, including allowance for fittings, etc.
k = unit cost of an increment of power-generating machinery, absolute units or dollars per fluid horsepower, as indicated.
l = length of pipe.
m = ratio of valve diameter to pipe diameter.
n = exponent of diameter in equation relating friction factor to diameter. (For smooth pipe the exponent of Reynolds number is $-n$.)
p′ = pressure loss per unit length of pipe (Figure 3) or loss in any given length, as indicated; e.g., equation (1).
r = rate of fixed charges, expressed as a fraction of the first cost, including depreciation, obsolescence, taxes, etc., and interest or profit on investment.
t = operating time, expressed either as a fraction of total time (load factor) or in seconds per annum, as indicated.
γ = exponent in pipe-cost formula.
ζ = ratio of pressure loss through a valve to the velocity pressure, referred to valve diameter.
η = combined coefficient of loss in valve and taper, referred to pipe diameter.
λ = arbitrary factor of proportionality (mentioned as sometimes used instead of f by other writers but not so used here).
μ = absolute viscosity in units consistent with system used.
$v = \frac{\mu}{\rho}$ = kinematic viscosity in absolute units.
ξ = coefficient in Borda's formula for loss in expanding tapers.
π = ratio of circumference to diameter.
ρ = fluid density, absolute units consistent with system used, or pounds per cubic foot, as indicated.
ϕ = function of pipe diameter in pipe-cost formula.

Application of Superheated Steam to Combination-Unit Prime Movers

By A. E. HARNSBERGER
The Pure Oil Company, Chicago, Illinois

THIS paper summarizes an investigation made by a refiner on the best method to meet the power requirements of a 25,000-barrel crude-charging-capacity combination unit. It was necessary to adapt the installation to meet the limited steam-production facilities in an existing plant.

The investigation revealed the practicability of generating steam from waste heat. By superheating the steam to the largest power-consuming units, and by condensing the steam from these units under vacuum, it was possible to reduce the steam requirements and make a boiler-house extension unnecessary. The paper gives operating data showing that original design expectations are being achieved.

This paper was presented to Division of Refining, before the Tenth Mid-Year Meeting of the American Petroleum Institute, at the Texas Hotel, Fort Worth, Texas, May 29, 1940.

COMBINATION cracking units of large capacity, involving as they do heavy pumping loads, present a power problem to the refiner. This is particularly the case in refineries in which the capacity of the unit represents a major fraction of the crude throughput. In the case under discussion it was necessary to take care of the power requirements of a unit having a crude-oil capacity of 25,000 barrels per day. It was necessary also to maintain operation of existing equipment over the trial period of the new unit.

The additional power requirements of the new operation analyzed as follows:

	Horsepower
Hot-oil pumps above 200 hp	2,000
Hot- and cold-oil pumps below 200 hp	1,200
Water circulation and forced-draft cooling	850
Total	4,050

The simplest solution to the problem would have been the purchase of the additional power. However, completely satisfactory continuity of service, particularly under southern climatic conditions, cannot be expected and, in addition, a lower-cost form of power was considered necessary for economical operation. Excellent results with gas or Diesel engines for cracking-coil feed-pump drives have been obtained, but in this case such equipment was not considered because of the large horsepowers involved.

Steam-power drive offered attractive possibilities. Its reliability is well-known, being subject to a minimum of interruptions. It also allows a maximum of flexibility, permitting easy variation of pump performance to suit conditions, with a minimum power loss because of throttling—a condition that hardly can be avoided in the case of constant-speed electric drives.

The boiler plant of the refinery was carrying a load near its normal maximum at the time the new unit was decided upon. Its enlargement was not desired in view of future plant operations. Attention, therefore, was given to steam generation on the unit by means of waste heat. Our experience with waste-heat generation, which dates back for many years, has been very satisfactory. In the early installations the generation of steam was limited to the order of 50 pound pressure because of low waste-heat temperatures. However, on later installations, involving high-pressure fractionation, generation at pressures up to 150 pounds has been found to be entirely practical.

The heat balance of the unit showed that a genera-

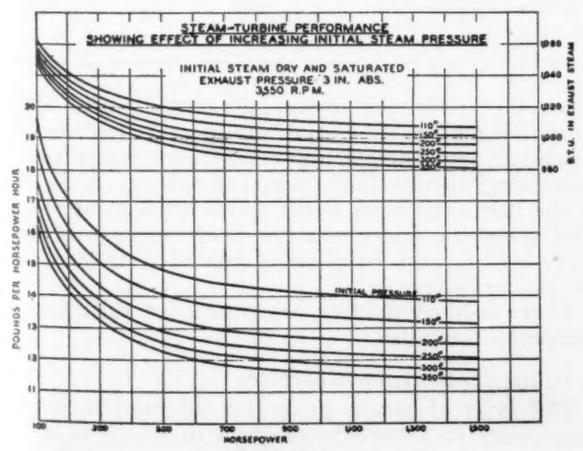


FIGURE 1

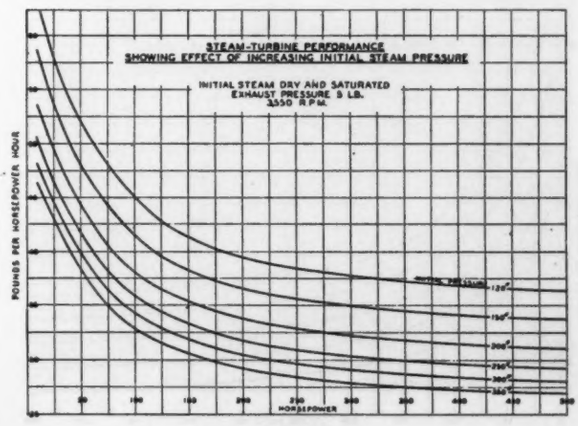


FIGURE 2

tion of 42,000 pounds per hour was possible. It was decided to apply this power to pump drives—supplementing, as needed, either with steam from the refinery boiler plant when available or by purchased electricity. Maximum brake-horsepower development with this quantity of steam was desirable for the following reasons:

1. To permit, if possible, the unit to operate on self-generated steam only.
2. To reduce condensing-water requirements.
3. To reduce operating costs.

Economy could be obtained by:

1. Raising initial steam pressure.
2. Superheating the steam.
3. Vacuum condensation.

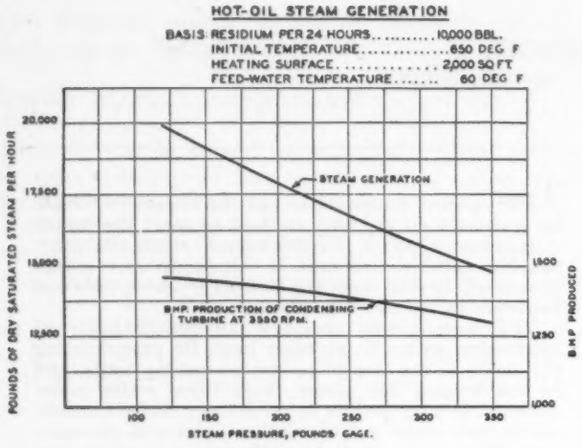

HOT-OIL STEAM GENERATION
BASIS: RESIDIUM PER 24 HOURS.....10,000 BBL.
INITIAL TEMPERATURE.....650 DEG F
HEATING SURFACE.....2,000 SQ FT
FEED-WATER TEMPERATURE.....60 DEG F
STEAM GENERATION
B.H.P. PRODUCTION OF CONDENSING TURBINE AT 3550 R.P.M.
POUNDS OF DRY SATURATED STEAM PER HOUR
B.H.P. PRODUCED
STEAM PRESSURE, POUNDS GAGE.

FIGURE 3

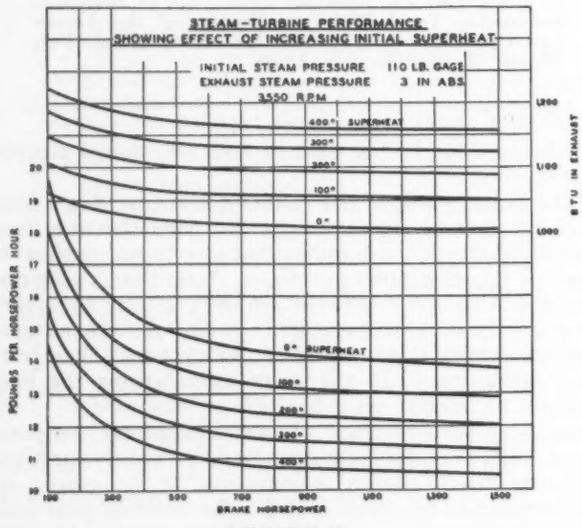


FIGURE 4

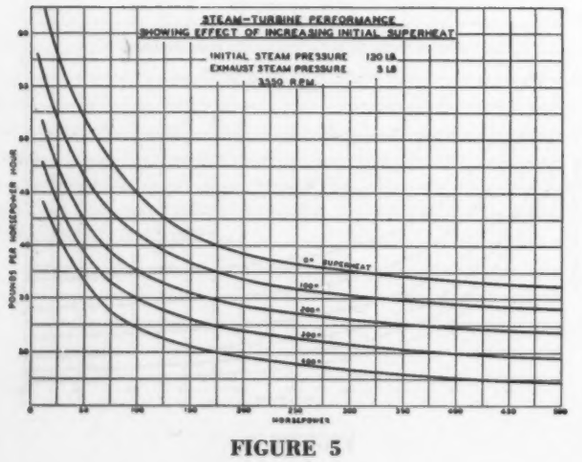


FIGURE 5

1. Effect of Pressure

The effect of pressure on the steam rate of both condensing and non-condensing turbines is shown in Figures 1 and 2. It will be noted that decided savings in steam are possible. However, under the conditions being discussed, an increase in pressure results in decreased brake-horsepower production because of rapid decrease in steam generation, as illustrated in Figure 3. This is accounted for by the decreased amount of heat available in the hot oil at higher steam temperatures. Generation of steam at 125 pounds, gage, was decided upon.

2. Effect of Superheat

The effect of superheat on both condensing and non-condensing turbines is shown in Figures 4 and 5. It will be noted that decided savings are possible, the direct result being decreased steam-generator or boiler capacity for a given load. In addition, there is a worth while overall heat economy, as shown in Figure 6. In Figure 6 is illustrated heat input to a separately fired superheater, and the extent to which this heat is offset by saving in heat input to boilers. Superheat also greatly reduces turbine-blade erosion, a serious factor when moisture content of steam is high. Superheat of 300° F was decided upon.

3. Effect of Vacuum Condensation

As shown by comparison of charts, vacuum condensation will reduce by more than half steam consumption for a given power. Three inches of mercury absolute condensing pressure was chosen because of 90° F water temperatures during summer seasons, and to restrict water consumption to a reasonable figure.

The driving turbines of the following pumps were selected to operate on superheated steam and condensing:

	Horsepower	Water Rate (Pounds per Brake Horsepower per Hour)	Steam Consumption (Pounds per Hour)
1. Clean recycle oil-furnace charge	1,000	11.5	11,500
2. Viscosity-breaker oil-furnace charge	450	12.2	5,500
3. Gas-oil oil-furnace charge	275	13.2	3,650
4. Reformer oil-furnace charge	275	13.2	3,650
Total	2,000	....	24,300

As the estimated steam generation was 42,000 pounds per hour, this left 17,700 pounds per hour for miscellaneous smaller non-condensing pump drives, processing purposes, and air-removal jets. A number of the non-condensing pump drives were arranged for dual steam-electric operation, both because of flexibility and for the purpose of guarding against electric-power failure.

There follows a brief description of the essential equipment installed:

a. Waste-Heat Steam Generator

The type of steam generator adopted is unique. It consists of a horizontal drum in which is held a constant water level by the feed-water pump. Ranged

alongside in vertical position are six tubular exchangers, the shell sides of which are connected to the drum. Water is fed from the drum into the lower section of the shells, the circulation being thermosyphon. Recycle oil, topped crude, and residuum are pumped through the exchangers. After 18 months of operation this waste-heat generator has proved to be entirely satisfactory, operating with a minimum of trouble and expense. The feed water is zeolite-treated to zero hardness, resulting in freedom from scale deposits on the outside of the tubes. The inside of the tubes of the exchanger, which operates on 10-gravity residuum, requires the most cleaning. Cleaning periods of these tubes average 6 months. Cleaning is accomplished by blowing close-fitting rubber stoppers through the tubes by the use of compressed air. Sectional elevation of the generator is shown in Figure 7; plan, in Figure 8; photographs in Figures 9 and 10.

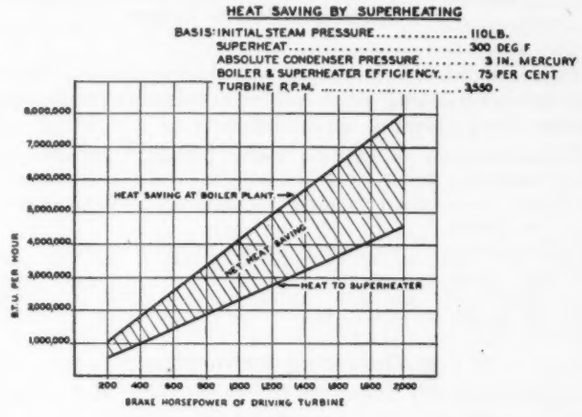

HEAT SAVING BY SUPERHEATING
BASIS: INITIAL STEAM PRESSURE..... 110LB.
SUPERHEAT..... 300 DEG F
ABSOLUTE CONDENSER PRESSURE..... 3 IN. MERCURY
BOILER & SUPERHEATER EFFICIENCY..... 75 PER CENT
TURBINE R.P.M. ..... 3550.
HEAT SAVING AT BOILER PLANT
NET HEAT SAVING
HEAT TO SUPERHEATER
B.T.U. PER HOUR
BRAKE HORSEPOWER OF DRIVING TURBINE

FIGURE 6

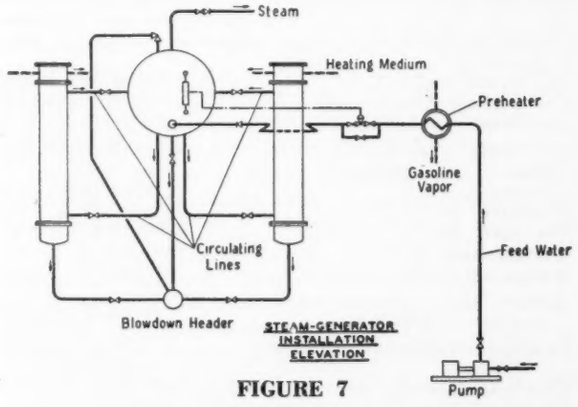


FIGURE 7

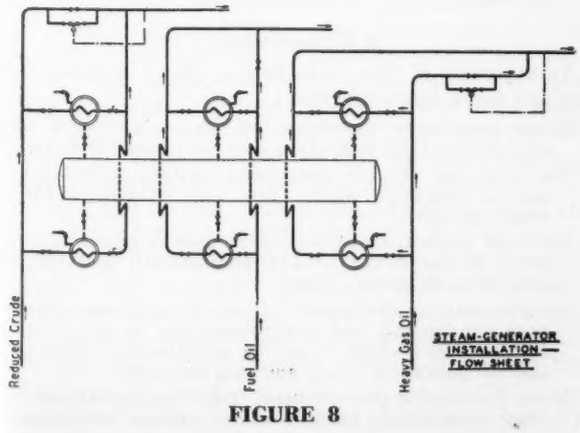


FIGURE 8

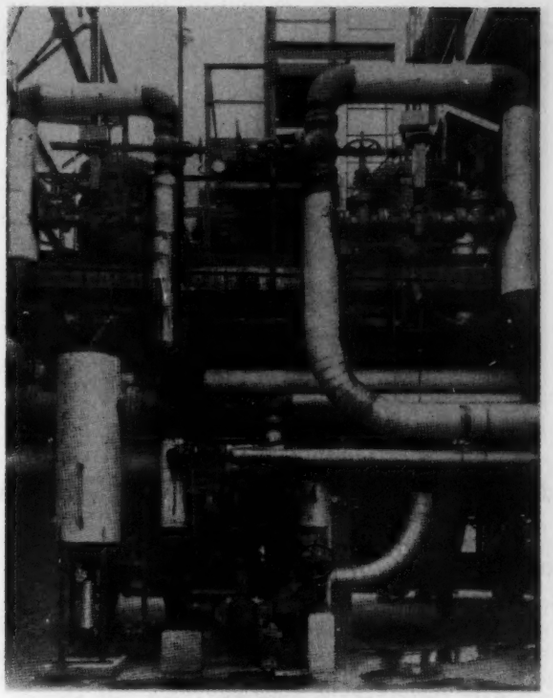


FIGURE 9
End Elevation of Steam Generator.

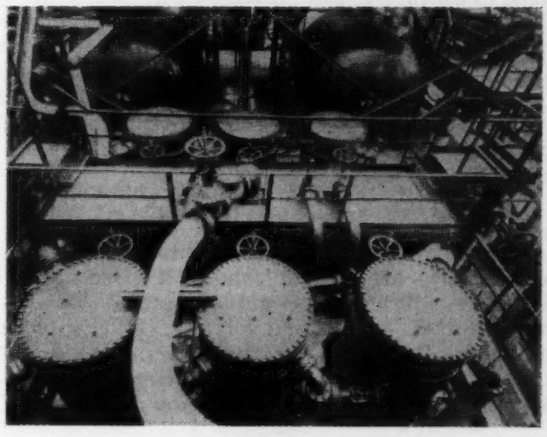


FIGURE 10
Top View of Steam Generator.

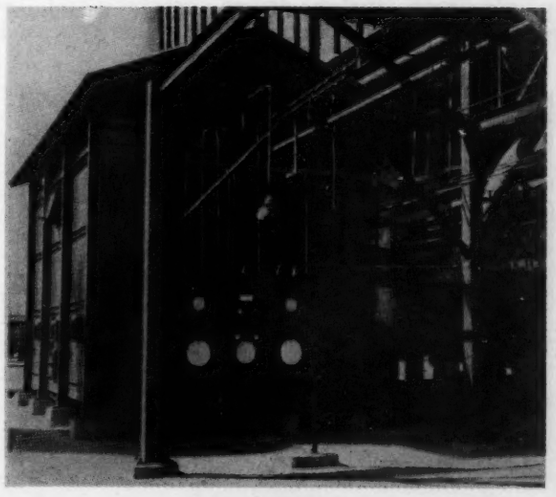


FIGURE 11
Steam Superheater Having a Capacity of 30,000 Pounds Per Hour.

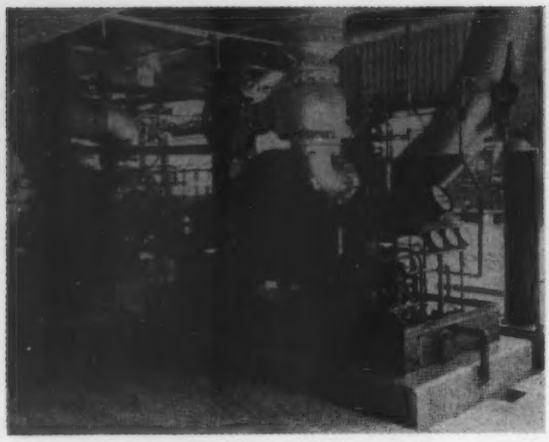


FIGURE 12
1,000 Horsepower Condensing Turbine Driving 6-Inch 6-Stage Clean-Oil Furnace Charging Pump.

b. Steam Superheater

Several methods of superheating that portion of the generated steam to be consumed by the condensing turbines were considered. At first, thought was given to utilization of waste heat in the flue gases from the clean-oil heater. The estimated cost of utilizing this heat was high because of the large amount of surface required. Also additional draft was required, resulting in a greater stack height. Furthermore, the possibility of tube failures necessitated temperature-control features to prevent excessive steam temperatures. As a result of this study it was decided not to use waste flue gas as a source of superheat, but to install a separately fired unit. The unit is shown in Figure 11.

c. Turbines

Turbines operating on superheated steam are standard units fitted with cast-steel governor-valve bodies and nozzle rings, monel-metal blading and monel-trimmed governor valves. Governing and variable-speed control are through oil-pressure relays. Installation of one 1,000-horsepower unit is shown in Figure 12. Others are shown in Figure 13.

d. Condensing Equipment

Individual barometric jet condensers were decided upon for each turbine-driven cracking-coil feed pump. An investigation showed that this type of installation would not cost any more than a central system consisting of a single condenser, and would have the following advantages:

1. Simplification of exhaust-steam piping, eliminating the necessity for a large header inside of the pump room.
2. Better year-round vacuum because of less difficulty with air leaks.
3. Elimination of water-seal valves in exhaust lines.
4. Any derangement of the condensing system would affect only one unit rather than all units. Installation is shown in Figure 14.

FIGURE 13
Three of Six Condensing Turbine-driven Hot-Oil Charge Pumps.

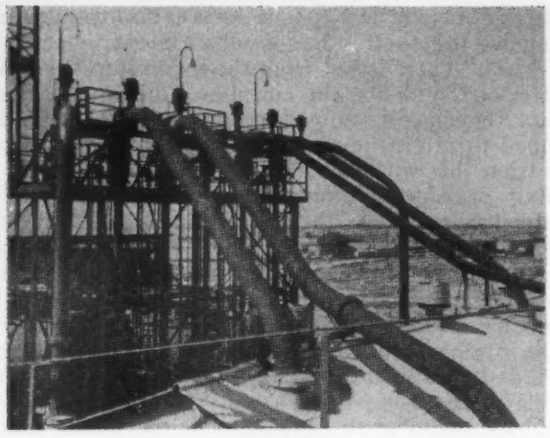


FIGURE 14
Barometric-Jet-Condenser Installation Serving Turbine-driven Hot-Oil Pumps.

4. Operating Performance

Data recently taken at the plant from the installation operating under average conditions show the following performance:

(1) Cracking-plant throughput.....25,740 bbl of crude oil per 24 hours.

(2) Steam produced from steam generators at 128 lb, gage, pressure:

(a) From fuel oil	16,100 lb per hour
(b) From reduced crude	9,200 lb per hour
(c) From cycle oil	14,100 lb per hour
Total	39,400 lb per hour

(3) Steam to superheater:

Volume	26,400 lb per hour
Pressure in	125 lb
Pressure out	122 lb
Temperature in	353° F
Temperature out	645° F

(4) Excess steam to non-condensing units and for processing.....13,000 lb per hour

(5) Average condensing vacuum..... 3½ in. mercury, absolute

Condensing-water inlet temperature, 66° F
Condensing-water outlet temperature, 99° F
Condensing-water consumption, 1,840 gal per min

5. Conclusions

As a result of this installation, the following conclusions have been reached:

a. Steam generation by means of waste heat is a thoroughly practical procedure on oil-processing units.

b. The first cost of such generating equipment will run as low as one-third of the first cost of boilers for an equal capacity.

c. Although generation at high pressures is practical, pressures in the order of 125 pounds will give greater utilization in most cases.

d. Superheating of the steam consumed by prime movers, both condensing and non-condensing, is an economical procedure—both from the standpoint of first cost, and of operating costs and maintenance.

e. When barometric jets are used, individual installation for each condensing turbine offers definite advantages.

Some Variables in Filter Clays

By L. M. HENDERSON, C. M. RIDGWAY, and W. B. ROSS
The Pure Oil Company, Chicago, Illinois

THE influence of water, carbon, and porosity on the filter efficiencies of Florida clays used on Pennsylvania cylinder stocks and bright stocks was investigated. In addition, a limited number of tests were made on bauxite clays.

It has been observed that the water is present in the clay in two states of affinity. Part of the water may be held loosely and removed readily at temperatures of about 450° F., whereas another part of the water is held more tenaciously, and is removed completely only on heating to almost 1800° F. The former type of water has been termed "adsorbed" water; the latter, "bound" water. The filter efficiency of a Florida clay decreases appreciably if the bound-water content is less than 2 percent. The adsorbed moisture affects appreciably the efficiency of the Florida clay. Inasmuch as freshly roasted Florida earth picks up moisture from the air rapidly at atmospheric temperatures, it is shown that the handling and storage of the clays, subsequent to their burning and prior to filtration, is an important factor in maintaining the filter efficiency of the clay.

The presence of carbon affects adversely the yield and cast of Pennsylvania cylinder stocks of 8 NPA color. The influence of carbon on a 5 NPA bright stock is not as great. The filter efficiency of Florida earth increases with porosity, inasmuch as the total surface area per gram of clay is a function of the porosity of the clay.

This paper was presented to Division of Refining, before the Tenth Mid-Year Meeting of the American Petroleum Institute, at the Texas Hotel, Fort Worth, Texas, May 29, 1940.

IT is well-known that the water content and porosity of percolation filter clays, as well as the carbon content of used clay, may be varied by suitable treatment, and thus affect the yield, haze point, and bloom of oils filtered through them. The magnitude of the individual contribution of each of these variables is not general knowledge. This investigation was made to evaluate these variables independently, in order to obtain practical and somewhat basic rules to guide the operator in handling percolation clays. The greater part of the present study was made on Florida fullers earth roasted in wedge-type burners and used on Pennsylvania cylinder stocks in naphtha solution and on bright stocks. A lesser amount of work was done on bauxite.

To say that moisture in clays affects yields is not adequate, nor is the statement of much practical value unless amplified. A more critical consideration of moisture content of clay reveals that the water exists in the clay in two degrees of affinity. One part of this water appears to be given up readily and taken up by the clay. This water arbitrarily may be termed "adsorbed" water. Another part is held more tenaciously, and in this report is termed "bound" water. This distinction in the two states of water in the clay is important to a working knowledge of the percolation behavior of filter clays. A commercial Florida clay which has been dried normally at the mine does not take up any moisture from the atmosphere so long as it is held at a temperature of 450° F. If such clay is heated to constant weight at 450° F. and then exposed to the atmosphere at lower temperatures, it will take up moisture. The water thus taken up is called herein "adsorbed" water, and it is this adsorbed water which has a marked influence on filter yields and haze points, as will be shown hereinafter. In order to determine the conditions favorable to minimum amounts of adsorbed water in clay, samples of Florida earth containing no adsorbed water were exposed in thin layers on one pan of a balance, which pan was suspended in a constant-temperature oven supplied with air of definite humidities. In this manner the effect of humidity, as well as temperature, on the adsorbed-water content of the clay could be determined. The results of these tests are shown in Figure 1. The specific clay employed in these tests was a new Florida clay which had been roasted at a temperature of 1075° F., but had had no other treatment nor use. Therefore, it is colloquially called a No. 1 clay. (A No. 5 clay, for example, designates clay which has been roasted five times and been used in percolating oil four times; i.e., the roasting treatment precedes and succeeds each use of the clay in a percolation filter.) A "½" number, as used hereinafter, indicates the clay has not been burned after use. Thus No. 4½ clay has been burned and used four times.

A No. 1 Florida clay which has been roasted properly at 1075° F. does not contain at that temperature any adsorbed moisture. A sample of such clay was allowed to cool to room temperature in the absence of moisture. Aliquot portions of it then were exposed to air at various temperatures and humidities, as described above, and the rate of moisture pickup was measured. It is evident from Figure 1 that temperature, rather than humidity, primarily determines the rate and amount of water taken up by the clay; e.g., clay which has been roasted at 1075° F. will pick up about 1 percent adsorbed water in 2 minutes if placed in relatively thin layers at 80° F. in contact with air at 80° F. having approximately 100 percent humidity. Similar clay under corresponding conditions will pick up 3.6 percent moisture in 45 minutes, and about 5 percent moisture in a period of several hours. The same clay, however, at 275° F. in contact with air, as stated previously, will pick up only 0.4 percent in 2 minutes, 0.6 percent in 45 minutes, and will approach equilibrium at about 0.8 percent in several hours. In a qualitative way, similar moisture results have been observed for bauxite.

It will be observed in Figure 1 that the sample of clay exposed to air at 275° F.—which previously had

been saturated with water vapor at 80° F., and thus contained 156 grains of water per pound of air—took up substantially the same percent of adsorbed moisture as when this clay was exposed, at the same 275° F. temperature, to air which contained only 26 grains of water per pound of air (i.e., air saturated with water vapor at 32° F.). This is significant in

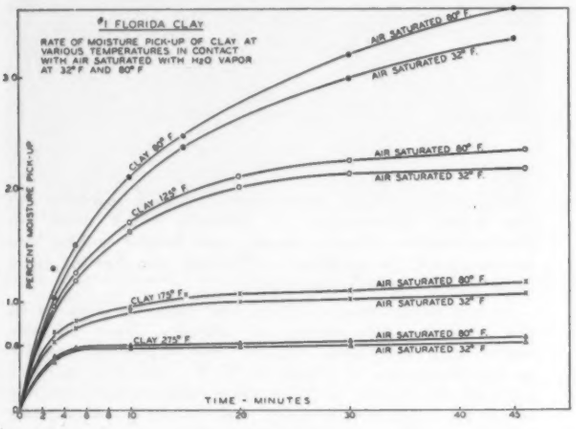

#1 FLORIDA CLAY
RATE OF MOISTURE PICK-UP OF CLAY AT VARIOUS TEMPERATURES IN CONTACT WITH AIR SATURATED WITH H2O VAPOR AT 32° F AND 80° F
PERCENT MOISTURE PICK-UP
TIME - MINUTES
CLAY 80° F.
CLAY 175° F.
CLAY 275° F.
AIR SATURATED 80° F.
AIR SATURATED 32° F.

FIGURE 1

plant operation, inasmuch as the thermal history of the clay and the extent of its exposure to air in the interval of time elapsing from the removal of the clay from the burner to the start of the filtration influence percolation yields.

In this investigation the "bound" water of an unused clay is defined arbitrarily as the loss in weight observed on heating to 1800° F. a sample of carbon-free Florida clay which previously had been dried to constant weight at 450° F. In the case of used clays containing carbon, it is necessary to remove the carbon by roasting the clays under suitable conditions. For such clays the "bound" moisture is considered the loss in weight on heating to 1800° F. a sample of the carbon-free clay which previously had been roasted to constant weight at 1075° F. The carbon content of the clays was determined by combustion analysis.

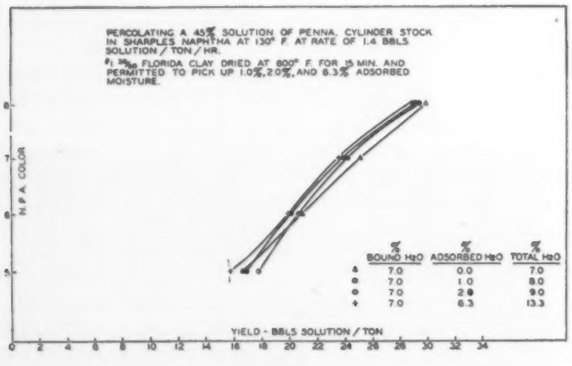

PERCOLATING A 45% SOLUTION OF PENNA. CYLINDER STOCK IN SHARPLES NAPHTHA AT 130° F AT RATE OF 1.4 BBLS SOLUTION / TON / HR.
#1 30/60 FLORIDA CLAY DRIED AT 800° F. FOR 15 MIN. AND PERMITTED TO PICK UP 1.0%, 2.0%, AND 6.3% ADSORBED MOISTURE.
N.P.A. COLOR
YIELD - BBLS. SOLUTION / TON
% BOUND H2O
% ADSORBED H2O
% TOTAL H2O
7.0 0.0 7.0
7.0 1.0 8.0
7.0 2.0 9.0
7.0 6.3 13.3

FIGURE 2

The effect of bound and adsorbed water upon percolation yields was studied, and it was observed that a variation in the bound moisture of a clay containing no adsorbed water had little, if any, direct detrimental effect on percolation yields, provided this moisture did not go below approximately 2 percent for Florida fullers earth (see Table 1). Table 1 shows bound-water contents only to 3.1 percent, which is typical of fresh, burned (No. 1) clay. However, additional tests (Table 1-**B**) have shown that on higher-number clays a minimum bound-moisture content of 2 percent is satisfactory. The data shown in Table 1 may seem to be too good to be true. However, these data were obtained on laboratory filters using the same oil, the same original clay, and were run at the

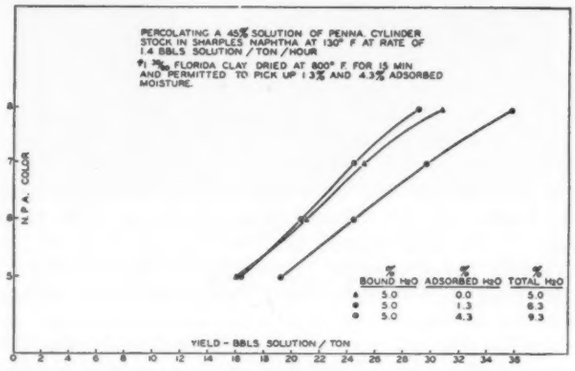

PERCOLATING A 45% SOLUTION OF PENNA. CYLINDER STOCK IN SHARPLES NAPHTHA AT 130° F AT RATE OF 1.4 BBLS SOLUTION / TON / HOUR
#1 30/60 FLORIDA CLAY DRIED AT 800° F. FOR 15 MIN AND PERMITTED TO PICK UP 1.3% AND 4.3% ADSORBED MOISTURE.
N.P.A. COLOR
YIELD - BBLS. SOLUTION / TON
% BOUND H2O
% ADSORBED H2O
% TOTAL H2O
5.0 0.0 5.0
5.0 1.3 6.3
5.0 4.3 9.3

FIGURE 3

same time. The NPA color scale is not sufficiently sensitive to show any variation. The bound-moisture content of the clay, moreover, appears to have an influence upon the amount of adsorbed water which a clay will pick up; and, further, variation in the amount of adsorbed water in a clay containing a large amount of bound water has less effect on filter yields than does a variation in the adsorbed water on a clay containing a small amount of bound moisture. This is illustrated in Figures 2, 3, and 4. When the No. 1 Florida clay had been dried at 600° F. and contained 7 percent of bound moisture, the filter yields were substantially the same for different quantities of adsorbed water. In the case of the same No. 1 Florida clay roasted at 1075° F. to a bound-water content of 3.1 percent, variations in the adsorbed moisture resulted in marked differences in filter yields, with a maximum yield for an adsorbed-water content of about 1 percent. Hence the thermal history of the clay, from the time it leaves the roaster

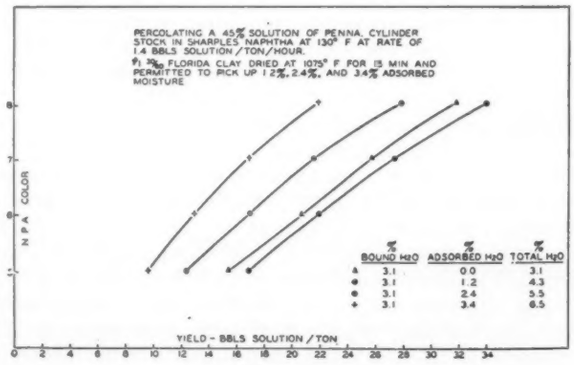

PERCOLATING A 45% SOLUTION OF PENNA. CYLINDER STOCK IN SHARPLES NAPHTHA AT 130° F AT RATE OF 1.4 BBLS SOLUTION / TON / HOUR.
#1 30/60 FLORIDA CLAY DRIED AT 1075° F FOR 15 MIN AND PERMITTED TO PICK UP 1.2%, 2.4%, AND 3.4% ADSORBED MOISTURE
N.P.A. COLOR
YIELD - BBLS. SOLUTION / TON
% BOUND H2O
% ADSORBED H2O
% TOTAL H2O
3.1 0.0 3.1
3.1 1.2 4.3
3.1 2.4 5.5
3.1 3.4 6.5

FIGURE 4

at 1075° F. to the time it is charged to the percolator, is important with respect to filter efficiency. From Figure 1 it is evident that, in order to keep the adsorbed-moisture content low, it is desirable to maintain the clay as free from contact with air or at as high a temperature as operating circumstances permit in the interval of passage of the clay from the roaster to the filter.

TABLE 1
Laboratory Filter—Temperature of Filtration, 130° F.

"A"

CLAY SAMPLE	Drying Temperature (°F.)	"Bound" Water (Percent)	"Adsorbed" Water (Percent)	Yields of Cylinder-Stock Solution (Barrels per Ton)			
				5 NPA	6 NPA	7 NPA	8 NPA
A	600	8.8	0.0	15.5	20.8	25.9	32.0
B	700	7.6	0.0	15.5	20.8	25.9	32.0
C	800	5.2	0.0	15.5	20.8	25.9	32.0
D	900	4.3	0.0	15.5	20.8	25.9	32.0
E	1,075	3.1	0.0	15.5	20.8	25.9	32.0

"B"

SAMPLE No.	Burn No.	Total Moisture (Percent)	Carbon (Percent)	Yields of Cylinder-Stock Solution (Barrels per Ton)			
				5 NPA	6 NPA	7 NPA	8 NPA
63C	1	3.0	0.0	18.4	22.5	26.0	30.3
63E	2	2.6	2.5	19.1	22.1	24.4	28.3
63G	3	2.1	1.7	17.4	21.1	23.8	28.1
69B	4	1.8	0.8	13.7	17.7	21.1	25.9
73B	5	1.3	0.4	11.9	13.9	16.8	21.0

Effect of Moisture Content upon Haze Point of Filtered Oils

The foregoing paragraphs have dealt chiefly with the effect of adsorbed moisture of clays on filter yields. When percolating neutrals or bright stocks at elevated temperatures through clay containing adsorbed moisture, it is significant that the finished product is hazy. Here again the distinction between bound and adsorbed moisture is important, for a clay containing 7.0 percent of bound water and practically 0 percent adsorbed moisture produced clear trim-percolated bright stock without haze; whereas clay containing 3.0 percent combined moisture and 3.0 percent adsorbed moisture (a lower total moisture) produced a very hazy filtrate. The term "trim filtering" is used here to designate a filtration of bright stock which has been filtered in solution and subsequently reduced to flash and viscosity prior to the "trim" filtration (see Figures 5, 6, and 7). With the bauxite types of filter clays, it has been observed that the bound-moisture content may be reduced to a lower value than with fullers earth without ruining the filter efficiency; therefore, it will be noted in Figures 5 and 7 that the bound-moisture content of the bauxite clays is less than the usual 2 percent in the Florida clay (see Table 2). Under similar circumstances, filtration of a naphtha solution of bright stock through a clay containing adsorbed moisture will yield a hazy filtrate. In this instance, however, the haze is of no consequence, inasmuch as the moisture is driven out of the oil when the naphtha is removed by distillation.

Clays with high adsorbed-moisture content produced trim-percolated bright stocks with haze points of 120 to 130° F., whereas clays with little or no adsorbed moisture produced trim-percolated bright stocks with haze points approaching the pour points (presumably due to wax, and not to water).

Influence of Moisture on Cast of Oil

Our experiments indicate that the moisture content, either bound or adsorbed, of Florida fullers earth has no noticeable effect on the cast or bloom of the filtered oil. In the case of bauxite clays, however, this may be different; for in tests with a No. 20 bauxite, Pennsylvania bright stock was trim-percolated at a temperature of 250° F. through a No. 20 bauxite clay having an adsorbed-moisture content of 5.7 percent, and a filtrate of poor cast (bluish) was obtained. When filtered at the same temperature through another portion of this No. 20 bauxite clay containing 0.8 percent bound moisture with no adsorbed moisture, a filtrate of much better cast was obtained. In plant practice it has been observed that straining Pennsylvania bright stocks through bauxite at 350° F. gives better cast than straining or trim-percolation at lower temperatures.

Moisture Content of Clays Related to Carbon

There appears to be a rough quantitative relationship between moisture and carbon content of used clays, as shown in Table 3 (see Figure 8). From the data on a considerable number of reburned clays, it has been ascertained that, on roasting the used clay at 1075° F. for varying periods of time, the equilibrium value of about 2 percent of moisture is at-

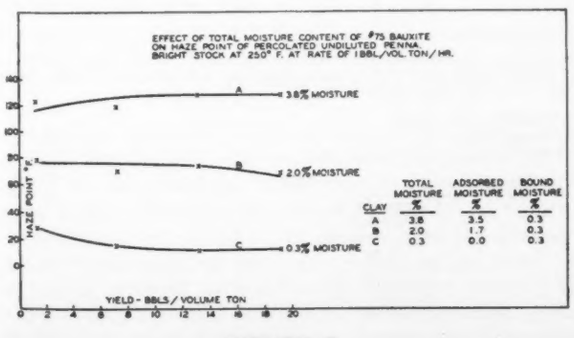


FIGURE 5

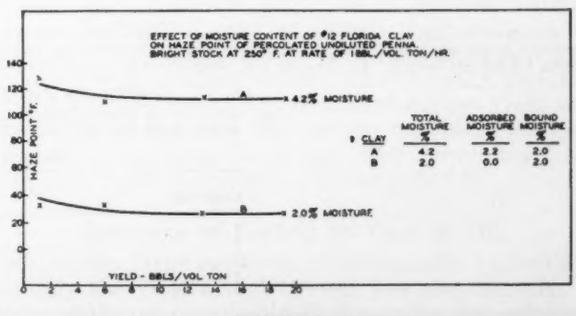

EFFECT OF MOISTURE CONTENT OF #12 FLORIDA CLAY ON HAZE POINT OF PERCOLATED UNDILUTED PENNA. BRIGHT STOCK AT 250° F. AT RATE OF 1BBL./VOL. TON/HR.
A
4.2% MOISTURE
B
2.0% MOISTURE
CLAY
TOTAL MOISTURE %
ADSORBED MOISTURE %
BOUND MOISTURE %
A 4.2 2.2 2.0
B 2.0 0.0 2.0
HAZE POINT °F.
YIELD - BBLS./VOL. TON

FIGURE 6

TABLE 2
Moisture Content and Haze Points

CLAY	Bound Moisture (Percent)	Adsorbed Moisture (Percent)	Approximate Haze Point (°F.)
No. 75 Bauxite	0.3	0.0	20
	0.3	1.7	75
	0.3	3.5	125
No. 20 Bauxite	0.8	0.0	19
	0.8	4.9	110
No. 12 Fullers earth	2.0	0.0	22
	2.0	2.2	116

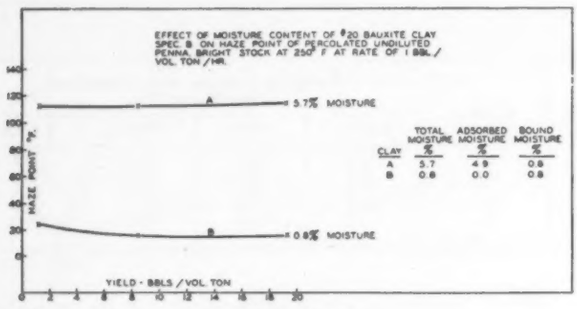

EFFECT OF MOISTURE CONTENT OF #20 BAUXITE CLAY SPEC. B ON HAZE POINT OF PERCOLATED UNDILUTED PENNA. BRIGHT STOCK AT 250° F AT RATE OF 1 BBL./VOL. TON/HR.
5.7% MOISTURE
0.8% MOISTURE
HAZE POINT °F.
YIELD - BBLS./VOL. TON
CLAY | TOTAL MOISTURE % | ADSORBED MOISTURE % | BOUND MOISTURE %
A | 5.7 | 4.9 | 0.8
B | 0.8 | 0.0 | 0.8

FIGURE 7

tained, and that this 2 percent represents bound moisture. It would appear, therefore, for used clays burned at 1075° F. and still containing carbon and an amount of moisture in excess of 2 percent, that the

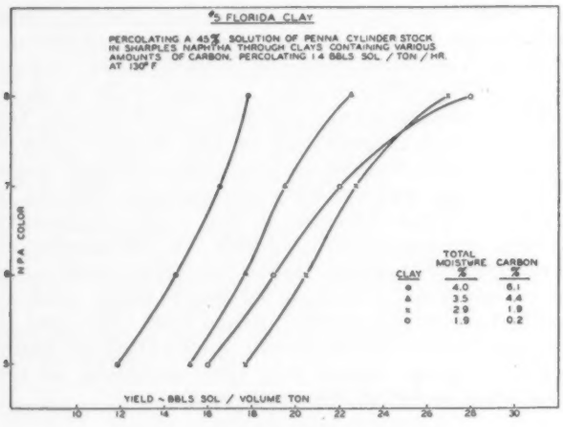

#5 FLORIDA CLAY
PERCOLATING A 45% SOLUTION OF PENNA. CYLINDER STOCK IN SHARPLES NAPHTHA THROUGH CLAYS CONTAINING VARIOUS AMOUNTS OF CARBON. PERCOLATING 1.4 BBLS SOL./TON/HR. AT 130° F
N.P.A. COLOR
YIELD - BBLS SOL./VOLUME TON
CLAY | TOTAL MOISTURE % | CARBON %
a | 4.0 | 6.1
b | 3.5 | 4.4
c | 2.9 | 1.9
d | 1.9 | 0.2

FIGURE 8

amount of moisture present in excess of 2 percent is adsorbed moisture. From Table 3, which is representative of many samples obtained from the refinery, it will be noted that the carbon content of the clay will be reduced to substantially zero, if the clay is heated for a sufficient time at 1075° F. The moisture content of the clay, however, appears to be reaching a minimum value of about 2 percent. The carbon and

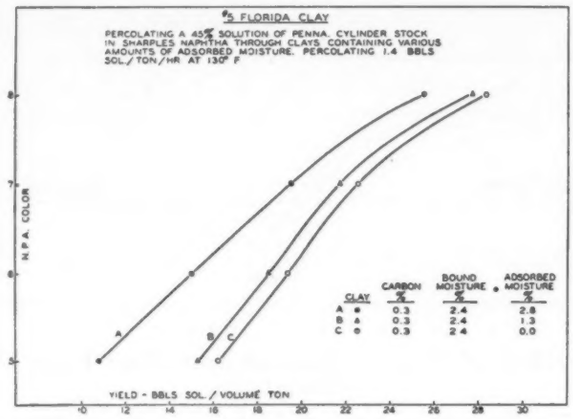

#5 FLORIDA CLAY
PERCOLATING A 45% SOLUTION OF PENNA. CYLINDER STOCK IN SHARPLES NAPHTHA THROUGH CLAYS CONTAINING VARIOUS AMOUNTS OF ADSORBED MOISTURE. PERCOLATING 1.4 BBLS SOL./TON/HR. AT 130° F
N.P.A. COLOR
YIELD - BBLS SOL./VOLUME TON
CLAY | CARBON % | BOUND MOISTURE % | ADSORBED MOISTURE %
A | 0.3 | 2.4 | 2.8
B | 0.3 | 2.4 | 1.3
C | 0.3 | 2.4 | 0.0

FIGURE 9

adsorbed moisture of the clay will reach zero if given sufficient time at 1075° F., but the bound moisture should remain at about 2 percent.

It was not feasible to obtain samples of clays containing no adsorbed moisture and varying amounts of

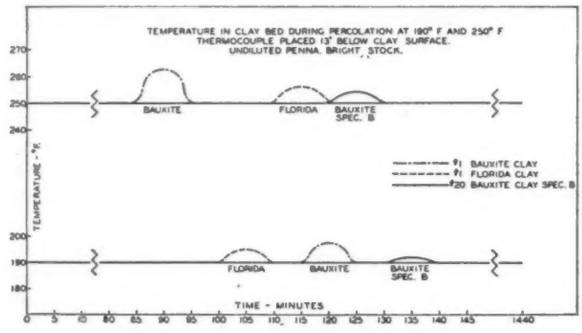

TEMPERATURE IN CLAY BED DURING PERCOLATION AT 180° F AND 250° F THERMOCOUPLE PLACED 13" BELOW CLAY SURFACE. UNDILUTED PENNA. BRIGHT STOCK.
BAUXITE
FLORIDA
BAUXITE SPEC. B
#1 BAUXITE CLAY
#1 FLORIDA CLAY
#20 BAUXITE CLAY SPEC. B
TEMPERATURE - °F.
TIME - MINUTES

FIGURE 10

TABLE 3
Effect of Carbon Content of Used Clays upon Percolation Yields
Samples of No. 4½ Florida clay were burned to various carbon contents and percolations carried out with the following results:

CLAY	Temperature of Burn (°F.)	Bound Water (Percent)	Adsorbed Water (Percent)	Carbon (Percent)	Yields of Solution (Barrels per Ton)				Cast or Bloom	
					5 NPA	6 NPA	7 NPA	8 NPA	5 NPA	8 NPA
E	900	1.9	2.1	6.1	11.9	14.5	16.5	17.8	(5+)* Bad	(5)* Bad
F	1,075	1.9	1.6	4.4	15.2	17.7	19.5	22.5	(5) Bad	(5) Bad
G	1,075	1.9	1.0	1.9	17.7	20.5	22.7	26.9	(4) Poor	(4) Poor
H	1,075	1.9	0.0	0.2	16.0	19.0	22.0	28.0	(3) Good	(2) Good

Standards for comparing the cast of bright stocks after percolation through clays containing various carbon contents were prepared by blending in various proportions a bright stock having a good cast from a percolation through new burned clay with a bright stock having a bad cast from a percolation through clay containing 4.4 percent carbon. The number and composition of the standards are indicated in the following tabulations:

ARBITRARY PRIMARY STANDARDS OF COST

(a) Bright stock after percolation through new burned clay.
(b) Bright stock after percolation through clay containing 4.4 percent carbon.

BLENDED STANDARDS

Cast No.	Composition (Percent)
1	100 (a)
2	75 (a)+25 (b)
3	50 (a)+50 (b)
4	25 (a)+75 (b)
5	100 (b)

* These cast numbers are from arbitrary cast standards.

TABLE 4
Distribution of Free Space in Percolating Clay

	FLORIDA CLAY					
	No. 1	No. 4	No. 5	(A)	Bauxite	Approximate Pore Radius
Roasting temperature, °F.	1,075 (approximately)	1,100 (approximately)	1,100 (approximately)	1,800	1,075	.....
Carbon, percent	0.0	5.5	3.2	0.0	0.0	.....
Total moisture, percent	2.9	5.1	2.8	0.0	0.6	.....
Total free space (voids and pores), cc per g	1.56	1.26	1.29	0.38	....	.....
Voids (pressure < 15 cm mercury), cc per g	0.38	0.21	0.24	0.38	*	5×10^{-3}cm
Total pore volume, cc per g	1.18	1.05	1.05	0	0.61	.....
Volume of pores filled with mercury at 30 psi, cc per g	0.44	0.58	0.43	....	0.25	3×10^{-4}cm
Volume of pores filled with mercury at 900 psi, cc per g	0.61	0.64	0.53	....	0 32	5×10^{-6}cm
Pores not filled with mercury at 900 psi, cc per g	0.57	0.41	0.52	....	0.29	.....
Total pore volume not filled at 900 psi, percent	48	39	49	....	47	.....
Percolation yield, barrels of 45 percent solution Pennsylvania cylinder stock per ton for net oil of 6 NPA	19.6	14.0	19.7	....	11.6	.....

* Not determined.

carbon. For the effect of fixed percent carbon and varying amount of adsorbed water on filter yields, see Figure 9.

Effect of Clay and Temperature on Flash Point of Trim-filtered Bright Stock

The addition of oil to dry clay develops some heat. With bright stocks this is quite noticeable at elevated temperatures; e.g., in a laboratory filter 2 inches in diameter and 26 inches deep, containing 1200 cc. of clay, a thermocouple placed at the center of the filter showed a temperature rise of 12° F. with a No. 1 bauxite, a 6° F. temperature rise with No. 1 Florida fullers earth, and a 4° F. rise with a No. 20 bauxite clay, when percolating Pennsylvania bright stock at a filter temperature of 250° F. At the time this temperature was taken, the oil was flowing through the clay at a rate of about 0.15 inch per minute (see Figure 10). In actual plant practice extreme temperature rises of 100° F. in the clay bed have been reported, when soaking the clay with oil.

The temperature at the location of the thermocouple rises for a short time as the oil proceeds down the clay bed, reaches a maximum in a relatively short time, and then falls off to the filter temperature.

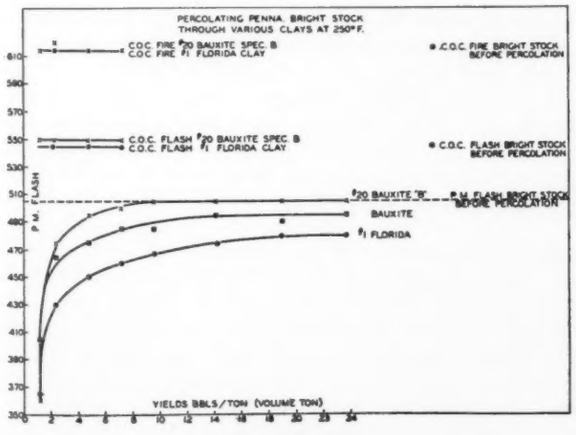

PERCOLATING PENNA. BRIGHT STOCK THROUGH VARIOUS CLAYS AT 250°F.
C.O.C. FIRE #20 BAUXITE SPEC. B
C.O.C. FIRE #1 FLORIDA CLAY
C.O.C. BRIGHT STOCK BEFORE PERCOLATION
C.O.C. FLASH #20 BAUXITE SPEC. B
C.O.C. FLASH #1 FLORIDA CLAY
C.O.C. FLASH BRIGHT STOCK BEFORE PERCOLATION
#20 BAUXITE "B"
P.M. FLASH BRIGHT STOCK BEFORE PERCOLATION
BAUXITE
#1 FLORIDA
P.M. FLASH
YIELDS BBLS/TON (VOLUME TON)

FIGURE 11

Presumably, this rise of temperature proceeds down through the bed of clay as the oil advances, and is related to the cracking observed in trim-filtering of bright stocks. During the initial period of percolation such evidence of cracking is afforded by the Pensky-Marten flash point of successive cuts taken from the filter, as compared to the Pensky-Marten flash of the charge (see Figure 11). This temperature rise apparently is not related directly to flash-point lowering, inasmuch as the No. 1 bauxite showed higher flash points on the filtrate than did No. 1 Florida fullers earth—although the former showed a greater temperature rise in the clay bed. A No. 20 bauxite showed the smallest temperature rise in the filter bed and the least effect on flash points. Trim-percolation at 190° F. had less effect on flash points than did filtration at 250° F. (see Figure 12). The amount of cracking is obviously small in each of the above cases, inasmuch as the Cleveland open-cup flash of the filtrate was not affected. In the Cleveland open-cup test a small amount of light material evidently is distilled off before the flash point of the liquid is obtained and, therefore, the Cleveland open-cup flash points of the filtrate and charge were substantially the same.

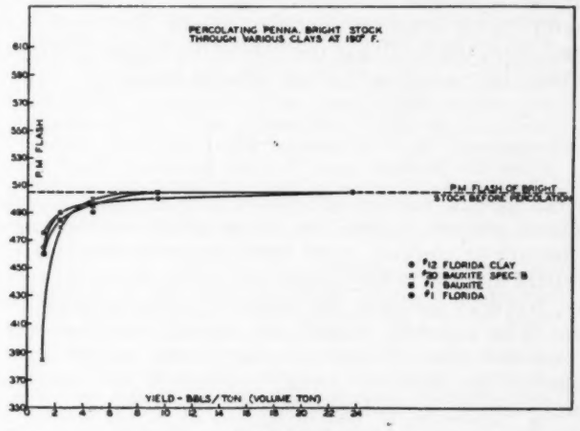

PERCOLATING PENNA. BRIGHT STOCK THROUGH VARIOUS CLAYS AT 190° F.
P.M. FLASH
P.M. FLASH OF BRIGHT STOCK BEFORE PERCOLATION
#12 FLORIDA CLAY
#20 BAUXITE SPEC. B
#1 BAUXITE
#1 FLORIDA
YIELD - BBLS/TON (VOLUME TON)

FIGURE 12

Effect of Carbon on Filter Yields

An examination of Table 3 reveals the tendency of the yields of 8 NPA Pennsylvania cylinder stock to increase as the percent carbon decreased; the yields of 5 NPA cylinder stock, however, increased as the percent carbon decreased to 1.9 percent, and then decreased with a further decrease in percent carbon. Other experiments have confirmed these data to the effect that for 8 NPA color the yield decreased continuously with percent carbon, whereas with yields of 5 NPA cylinder-stock filtrates a maximum yield was attained at about 2 to 2½ percent carbon. This generalization assumes, however, that previously the sample had not been heated above 1075° F.

Influence of Carbon on Cast of Oil

Relatively large amounts of carbon affect adversely not only the yield of 8 NPA oil, but also the cast or bloom of the oil (see Table 3). As a rule this influence

on bloom is more noticeable for 8 NPA filtrates than for lighter cuts, such as 5 NPA. Although removal of carbon from a clay by burning at too high a temperature may ruin filter yields, it does not ruin the cast of filtrates. To get a reburned clay of proper carbon and moisture, it should be heated long enough at a low enough temperature—1075° F. or less—to remove carbon and adsorbed water, but not to lower the bound-water content below 2 percent.

Porosity

The decolorizing power of percolation clay generally is assumed to be related to the nature of the surface of the clay and to the total area of surface. The surface area of a specific weight or volume of clay of a stated mesh size is related, in turn, to the number and sizes of the pores in the clay particles. Obviously, the surface of a given volume of small pores is greater than for the same volume of large pores.

By means of a method suggested by E. W. Washburn, it should be possible to determine the fraction of the total free space (or porosity) in the clay due to pores of specified effective diameters, or having diameters lying between specified limits. The method is based upon the fact that the pressure required to force mercury into a capillary of radius r is equal to:

$$-\frac{2\gamma \cos \theta}{r}$$

where: γ is the surface tension of mercury, and θ is the angle of contact. Some data are available on the angle of contact of mercury with clay; however, for strictly comparative purposes of samples of similar types of clay, we may assume the angle of contact to be the same. The volumes of mercury forced into the pores of two samples of clay of comparable composition, subjected to mercury under pressures of specified limits, afford information as to the volume of the pores having radii corresponding to the mercury pressures exerted. Thus, without determining the actual value of the radii, a comparison can be made as to the fraction of the porosity due to small pores and large pores, and the relative amounts of each in two clays of similar composition.

The porosity of a No. 1 Florida clay which had been roasted at 1075° F. was compared with the same kind of No. 1 clay roasted at 1800° F. The No. 1 clay dried at 1075° F. was found to contain 48 percent of its total pore volume as pores or microscopic fissures having an effective radius of less than 5×10^{-6} cm. The sample roasted at 1800° F. contained no pores nor apparent fissures having an effective radii as small as approximately 5×10^{-3} cm.

As a matter of theoretical interest, Table 4 is presented herewith to give some approximate indication of the pore volume and distribution of pore sizes of a few clays investigated. The filter yields are included to show that there is a qualitative relationship between filter yield and surface development or surface area of the respective samples of clay. Adsorbents of widely different chemical composition cannot be compared in this way.

Summary

For fullers earth, bound water (provided it is not below 2 percent) does not affect percolation filter yields. However, the higher the bound-water content of the clay, the greater the affinity of the clay for adsorbed water. Also bound water has no effect on haze point nor on cast of bright stock.

The adsorbed-water content, if above 1 percent, decreases filter yields. Adsorbed water causes haze in the filtered oil, but does not change the cast. The temperature of the clay and the time of exposure are much more important than humidity in determining the amount of adsorbed moisture which is picked up from contact with the air.

An excess of carbon, caused by burning at too low a temperature or for too short a time, reduces the yields when dark-colored stocks are desired, and impairs the cast.

The volume and size of the pores in a filter clay are related directly to filter yields.

Acknowledgment

The authors wish to acknowledge the assistance of W. Grant Annable, J. L. Binder, and E. P. King.

Removal of Sulfuric-Acid Fog by Bubble-Phase Absorption

By D. W. BRANSKY and F. F. DIWOKY
Standard Oil Company (Indiana), Whiting, Indiana

VARIOUS methods of the removal of H_2SO_4 droplets from the stack gases of sulfuric-acid manufacturing and concentrating plants have been evaluated. The various known methods have been divided into two categories, viz., effective and ineffective, according to the practicability of the method from both the viewpoint of sulfuric-acid removal and the economic picture. Effective methods such as: 1, the filtration of the stack gases through various wetted media; 2, the decomposition of acid mist by heating to 1000° F. or above under controlled conditions of combustion; 3, the use of Cottrell precipitators; 4, the use of steam ejectors with subsequent condensation of the steam; and 5, the use of turbomixers were discarded because of high investment or high operating costs. A new method, in which the gas is bubbled through an aqueous solution of a foam-producing substance, has been found to be extremely effective in removing H_2SO_4 droplets, and has a very low investment cost.

The most effective foam-forming agent found consists of the sulfonic acids obtained from the hydrolysis product of the acid sludge derived from the treatment of petroleum. These acids are readily soluble in water, form a relatively stable bubble phase in a dilute aqueous or sulfuric-acid solution, and are soluble in aqueous solutions of H_2SO_4 containing up to 10 percent acidity. A laboratory investigation, subsequently followed by a pilot-plant investigation, indicated that the method was effective in removing approximately 90 to 98 percent of the H_2SO_4 in the incoming gas, and that the efficiency of the H_2SO_4 removal was practically independent of the concentration of the H_2SO_4 in the gas and the temperature of the solution over ranges of 80 to 186° F. It was found also that the efficiency of removal was affected greatly by contact time. The pilot-plant experiments demonstrated that, with a contact time of 10 seconds to 11 seconds, approximately 93 to 95 percent of the total H_2SO_4 may be removed in continuous equipment having a pressure drop of approximately 2 inches of water. Economic calculations have indicated installations, operating, and repair cost to be approximately 50 percent that of equivalent electrical precipitation equipment.

This paper was presented to Division of Refining, before the Tenth Mid-Year Meeting of the American Petroleum Institute, at the Texas Hotel, Fort Worth, Texas, May 29, 1940.

THE concentration of sulfuric acid by the direct use of hot gases and the manufacture of sulfuric acid by the absorption of SO_3 in catalytic-acid plants both require operating conditions which result in the waste gases carrying varying amounts of SO_2, SO_3 and H_2SO_4 mist into the surrounding atmosphere. Concentration to high acidities generally requires the use of Cottrell precipitators, whereas concentration to acidities of from 60 to 70 percent H_2SO_4 frequently is accomplished without this protection—using only a packed tower to scrub entrainment from the effluent gases. From the viewpoint of nuisance, it is important to keep the sulfuric-acid content of the effluent gases at a minimum, and considerable effort has been expended here and elsewhere in the development of practical low-cost methods for the removal of acid mist from these waste products. It is, accordingly, the purpose of this paper to review a number of these methods which have been found to be effective in varying degrees, and to describe a new method of acid-mist removal, employing the principle of absorption in bubble films.

Except under abnormal circumstances, the evolution of SO_2 is not regarded as a serious nuisance problem, as this substance is a colorless gas and is dissipated readily in the surrounding atmosphere. In contrast, acid mist, which consists of non-volatile droplets, may maintain a characteristic fog formation over considerable distances. Sulfuric-acid fogs consist of very stable H_2SO_4 aerosols, which stability previous investigators[1,2] have shown to be due to the small particle size of H_2SO_4 droplets (1.1×10^{-3} to 1.6×10^{-4} cm in diameter) and the fact that the droplets are surrounded by adsorbed-gas films which prevent coalescence.

The following methods have been investigated here and elsewhere for their effectiveness in removing such mists from H_2SO_4 concentrator waste gases, and are classified hereinafter as; 1, ineffective and, 2, effective. Broadly speaking, the methods found ineffective either incompletely removed the acid mist or, because of economic circumstances, were found impractical. The methods found to be effective are discussed hereinafter somewhat more in detail.

1. Ineffective

a. Direct absorption in caustic solutions, H_2SO_4 solutions, water, oil, acetone, glycerin, ethyl alcohol, and various soap solutions.

b. Direct absorption in packed towers, employing countercurrent flow of water or dilute H_2SO_4.

c. Injection of steam into an air stream bearing H_2SO_4 mist and the subsequent condensation of the steam.

d. Use of high stacks for dispersion above local ground air currents.

2. Effective

a. *Filtration* through wetted filter pads, sintered glass plates, clay beds, or other finely foraminous materials.

This method provides for varying degrees of absorption in the filter medium, depending upon the conditions of shear which result from the filter medium used and

the velocities employed; but it has the practical disadvantage of a high-pressure drop across the filter.

b. *Decomposition* of acid mist by heating to 1000° F. or above under controlled conditions of combustion.

This method results in the dissociation of H_2SO_4 mist into SO_2, H_2O, and O_2—which allows for the rapid dispersion of these waste products into the atmosphere; but the fuel costs were found to be in excess of the concentrating costs, which had the effect of substantially doubling the acid-recovery fuel cost.

c. *Electrical precipitation* of H_2SO_4.

The installation of Cottrell precipitation equipment involves a substantial investment cost, particularly when this protection is considered in congested industrial areas which require complete elimination of the acid-mist nuisance.

d. The use of *steam ejectors* and the subsequent condensation of the steam.

This method is effective in that the acid mist is removed completely, but the high cost of steam and equipment is prohibitive.

e. *Turbo-mixers.*

Turbo-mixers effectively do away with the acid nuisance, but the power costs for such high-speed mixing devices generally are prohibitive in commercial installations.

f. *Direct absorption* in a foam phase which is produced by bubbling the H_2SO_4 mist through an aqueous solution of a foam-producing substance.

This method has been found to reduce the H_2SO_4 content of the entering gases 90 to 98 percent. The two principal advantages of this method are low-pressure drop and relatively inexpensive investment costs.

An examination of the methods shown hereinbefore indicated that only systems of low-pressure drop and relatively low investment and operating costs were economically feasible; and subsequent study in this laboratory on scrubber-type equipment, using suitable scrubbing solvents, justified this contention.

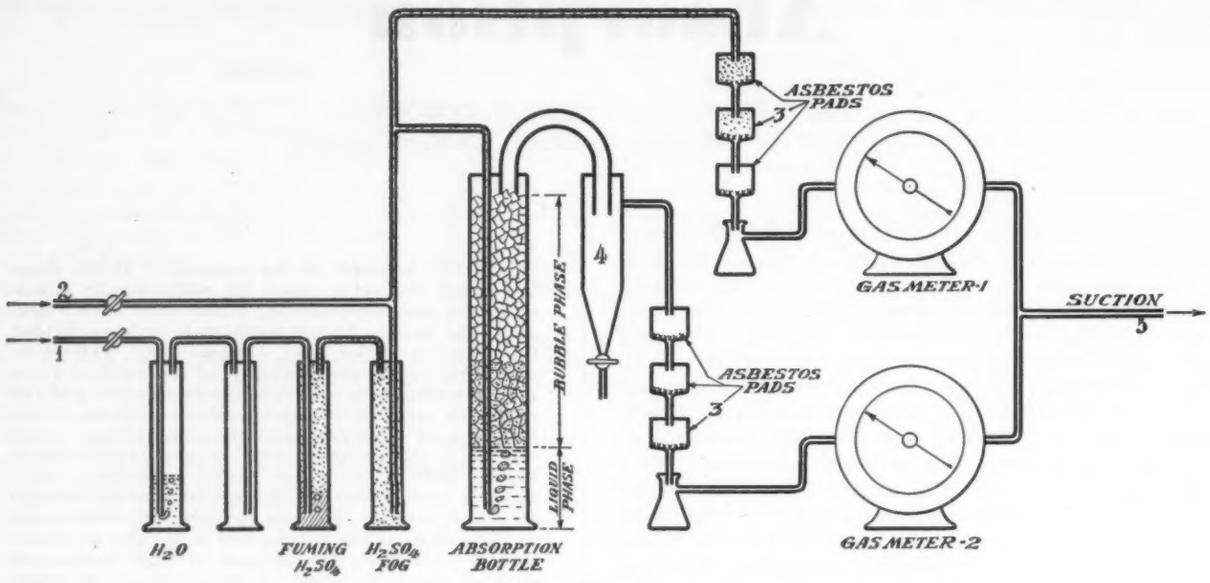


FIGURE 1
Laboratory Apparatus for Production and Absorption of Sulfuric-Acid Fog

The absorption of acid mist depends upon wetting the mist particles with the absorbing fluid. After the particles have been wetted and are in solution, there is very little tendency for the acid to revaporize because of the low vapor pressure of H_2SO_4 at the operating temperature. However, the individual mist particles, in all probability, are protected against wetting by an adsorbed-gas film; thus, to dissolve the particles, it is necessary to rupture the film. To accomplish this, relatively long times of contact over large absorbing surfaces are required. The effectiveness of scrubbing devices, therefore, may be seen to depend upon the extent of the contact surfaces offered.

Ordinary spray chambers, in which the wetting liquid flows countercurrently to the gases carrying the acid mist, have been proved inefficient. Likewise, bubbling the mist through liquid heads, which involves undesirable back pressure, is inefficient. It was found, however, that by the use of certain addition agents stable

TABLE 1
Comparison of the Effectiveness of H_2SO_4 Fog Absorption by Different Bubble-forming Agents

Conditions of Absorption:
Temperature of absorbing liquid =75-80 °F.
Approximate bubble size =0.25-in. to 0.5-in. diameter

AGENT	Concentration of Agent in Water (Percent by Weight)	Time of Contact of H_2SO_4 Fog in Bubble Phase (Seconds)	Concentration of H_2SO_4 Fog in Milligrams of H_2SO_4 per Cubic Foot of Gas		Percent of H_2SO_4 Absorbed
			Into the System	Out of the System	
1. Green acid	1.0	14.1	93.6	1.8	98.1
2. Commercial agent A	2.0	13.4	94.4	22.3	76.5
3. Commercial agent B	2.0	13.8	107.2	47.7	55.5
4. Commercial agent B	10.0	14.1	112.3	27.5	75.5

bubble layers could be built up upon the surfaces of the wetting liquid. In such a foam phase, H_2SO_4 fog was found to disappear to a degree almost directly proportional to the time of contact employed. On the basis of this observation, quantitative absorption data were obtained, and factors affecting absorption rates were investigated.

The most effective bubble-forming agent found was a sulfonated-acid mixture commonly referred to as "green acid," which is obtained upon the hydrolysis of the acid sludge derived from the treatment of petroleum. Although insoluble in H_2SO_4, these petroleum sulfonic acids are readily soluble in water, and sufficiently soluble in aqueous solutions of H_2SO_4 containing up to about 10 percent acidity to perform satisfactorily as foam-forming agents. The acid sludge itself may be used as a bubble-forming agent, but its efficiency is inversely proportional to the amount of free H_2SO_4 present. Both the sulfonated acid and the acid sludge lose their foam-forming properties when the acidity of the total solution reaches approximately 10 percent; but, in continuous operation, as the acid concentration builds up above 10 percent and the green acid becomes insoluble, it may be separated and recycled with the addition of fresh makeup water.

Although no quantitative determinations were made on the stability of the bubble phase in relation to the green-acid concentration, it appeared, from the behavior of the bubbles formed in concentrations of from 0.06 to 1.0 percent green acid, that a somewhat better head could be maintained at the higher concentrations. In pilot-plant work a head of approximately 6 feet of bubbles was maintained easily in continuous operation using 1 percent green acid in water.

Laboratory-Scale Investigation

The production of synthetic H_2SO_4 fog and the quantitative measurements of the absorption of this fog in the bubble layer produced from green-acid solutions were carried out in an apparatus shown in Figure 1. Air was drawn in through stopcock **1** and partially saturated with water vapor in the first wash bottle. After having passed through a safety bottle, the mixture was bubbled through fuming H_2SO_4 (104.5 percent acidity) which produced a dense white fog. The acid content of the fog was varied by diluting the mist with air which was admitted through stopcock **2**. The acidity of the fog was determined by drawing a sample through a series of three moistened asbestos filter pads. Using a layer of 0.5-inch asbestos in each section, the first pad was found to absorb 90 to 95 percent of the acid, and the second pad the remainder. Only upon rare occasions was any acidity detected in the last section. In the usual method of procedure, at the completion of each run the individual pads were washed with distilled water into a common flask, and the H_2SO_4 acidity determined by titration with standard caustic solutions. The fog acidity was expressed as milligrams of H_2SO_4 per cubic foot of dry gas at 60° F. The gas volumes were measured through calibrated gas meters. The percent H_2SO_4 absorption through the bubble phase was calculated from the difference in the H_2SO_4 content of the gas before and after passing through the bubble column. The bubble sizes were varied by raising or lowering the bubble tube in the absorption bottle or by changing the gas velocity through the absorbing solution. The time of contact for any given bubble size was varied by using foam bottles of different capacities or by using several foaming chambers in parallel.

A comparison of the effectiveness of bubble-phase absorption of H_2SO_4 fog in aqueous solutions of green acid and in two commercial wetting agents having foam-forming properties is shown in Table 1.

The sodium soap of green acid was found to be ineffective for producing a stable foam, as the soap in contact with free acid formed sodium sulfate. Iron salts formed water-insoluble iron soaps of the green acid, and likewise were ineffective. For example, the addition of ferric salts to the extent of 0.046 percent Fe to a 1-percent green-acid solution destroyed its foam-forming ability. Thus, the use of acid-resistant operating equipment (for example, lead- or brass-lined vessels) is essential.

It was observed that the acid concentration of the incoming fog had very little effect on the efficiency of the absorption. In a series of experiments in which the acid content of the incoming fog was varied from 8.1 mg to 845 mg of H_2SO_4 per cubic foot, the percent absorbed varied from 97.0 to 91.1. These data are summarized in Table 2.

In the foregoing experiments, the concentration of H_2SO_4 was varied by diluting the acid-fog stream with

TABLE 2
Absorption Vs. H_2SO_4 Concentration of the Gas

Conditions of Absorption:
Temperature of the green-acid solution =75 to 80 °F.
Concentration of the green-acid solution =1.0 percent
Approximate bubble size =0.25-in. to 0.5-in. diameter

	Time of Contact in the Bubble Phase (Seconds)	H_2SO_4 Content of the Gases (Milligrams of H_2SO_4 per Cubic Foot of Gas)		Percent of H_2SO_4 Absorbed
		Into the System	Out of the System	
1.	12.5	845	76.0	91.1
2.	14.1	93.6	1.8	98.1
3.	13.6	8.1	0.25	97.0

TABLE 3
Absorption Vs. Temperature

Conditions of Absorption:
Concentration of green-acid solution =1.0 percent
Approximate bubble size =0.25-in. to 0.5-in. diameter
Contact time of H_2SO_4 in the bubble phase=13 sec. to 14 sec.

Temperature of the Green-Acid Solution (°F.)	H_2SO_4 Content of the Gases (Milligrams of H_2SO_4 Per Cubic Foot of Gas)		Percent of H_2SO_4 Absorbed
	Into the System	Out of the System	
80	93.6	1.8	98.1
186	139.7	1.76	98.8

TABLE 4
Absorption Vs. Time of Contact in the Bubble Phase

Conditions of Absorption:
Concentration of green-acid solution =1.0 percent
Temperature of green-acid solution =70 to 75 °F.
Approximate bubble size =0.25-in. to 0.5-in. diameter

	Time of Contact of the H_2SO_4 Fog in the Bubble Phase (Seconds)	Concentration of H_2SO_4 Fog (Milligrams of H_2SO_4 per Cubic Foot of Gas		Percent of H_2SO_4 Absorbed
		Into the System	Out of the System	
1.	3.7	65.5	22.0	70.3
2.	3.7	80.9	16.4	78.5
3.	7.4	63.5	8.3	86.9
4.	13	83.5	3.6	95.6
5.	26	48.6	0.93	98.1
6.	39	46.4	1.31	97.3

TABLE 5
Bubble-Phase Absorption of H_2SO_4 Fog in Pilot-Plant Operation

Conditions of Absorption:
Concentration of green-acid solution=1.0 percent
Bubble size=varied in the bubble phase from 0.25-in. to 2.0-in. diameter
Temperature of gases into the bottom of the tower=150 to 160 °F.
Temperature of gases at top of the tower=110 to 120 °F.

Test No.	Number of Bubble Plates	Height of Bubble Phase (Inches)	Back Pressure On the Tower (Inches of H_2O)	Velocity of Gases (Feet per Second)	Time of Contact of the H_2SO_4 Fog in the Bubble Phase (Seconds)	Concentration of H_2SO_4 Fog (Milligrams of H_2SO_4 Per Cubic Foot of Gas)		Percent of H_2SO_4 Absorbed
						Entering System	Leaving System	
A-7	1	72	0.9	3.0	2	132.0	66.2	50.0
A-8	1	72	0.9	2.0	3	86.0	45.3	48.0
A-4	1	72	0.9	1.7	3.5	72.0	50.0	30.5
A-1	1	72	0.9	1.6	3.8	9.8	3.9	60.2
A-2	1	72	0.9	1.5	4.0	54.7	22.7	58.5
A-3	1	72	0.9	1.5	4.0	50.5	11.9	76.5
A-10	1	72	0.9	1.2	5.0	81.2	16.1	80.2
A-9	1	72	0.9	0.6	10.0	78.6	5.4	93.0
A-6	1	72	0.9	0.5	12.5	194.0	25.3	86.5
A-5	1	72	0.9	0.4	13.0	56.9	7.5	87.0
A-21	1	44	0.9	1.7	2.1	71.0	49.6	30.2
A-23	1	44	0.9	0.9	4.3	56.5	19.9	64.7
A-22	1	44	0.9	0.8	4.9	50.0	5.6	88.9
A-24	1	44	0.9	0.3	11.6	25.6	1.5	94.1
A-17	2	72	1.8	2.0	3.0	20.0	11.1	44.5
A-15	2	72	1.8	1.7	3.5	27.4	13.9	49.3
A-16	2	72	1.8	1.7	3.5	32.6	15.9	51.2
A-20	2	72	1.8	1.6	3.8	63.0	26.6	57.8
A-18	2	72	1.8	1.3	4.5	35.6	13.2	63.0
A-13	2	72	1.8	0.9	6.5	108.0	3.5	96.5
A-19	2	72	1.8	0.8	7.0	23.8	2.7	88.7
A-12	2	72	1.8	0.5	12.5	86.0	3.0	96.5
A-14	2	72	1.8	0.4	15.0	114.0	2.6	97.8

air while all other experimental conditions were held constant.

The effect of temperature on the ability of green-acid absorbing solutions to form stable bubbles was found not to be a controlling factor over the temperature range studied (70 to 186° F.). Laboratory experimental data over this temperature range are shown in Table 3.

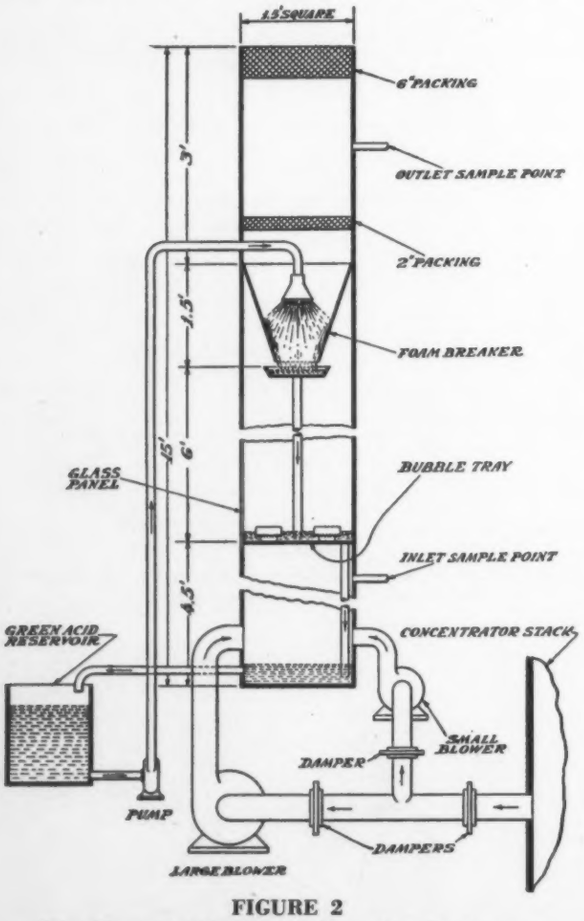


FIGURE 2
Pilot-Plant Bubble-Phase Absorption Equipment

The effect of time of contact between the H_2SO_4 fog and the bubble phase was determined by varying the foam volume either by using chambers of different sizes or by using multiple chambers in parallel, or by varying the velocity of the gas flow through the range 3.5 cm to 15.9 cm per second. The importance of this factor may be seen in Table 4.

Semi-plant-Scale Investigation

On the basis of the laboratory data reported hereinbefore, a 15-foot wooden pilot-plant scrubber was constructed adjacent to the effluent stack of a commercial hot-gas concentrator. The concentrator operated over the range 50 to 55 percent inlet acid to 65 to 70 percent outlet acid, and was provided with a packed tower containing ceramic rings for the reduction of H_2SO_4 entrainment. The normal operation of this unit produced effluent gases of from 40 mg to 80 mg of H_2SO_4 per cubic foot of dry gas. As shown in Figure 2, H_2SO_4-bearing gases were drawn from the concentrator stack by means of one or both blowers, and forced into the bottom of the tower. Dampers were installed at the positions indicated for regulating the volume of gas introduced to the system. Saw-toothed bubble caps insured an adequate formation of bubbles, which completely filled the section between the bubble tray and the foam breaker. The green-acid solution was circulated by a pump from the green-acid reservoir to the foam-breaker section, and was effective in destroying all bubbles entering this section. The green acid then passed to the bubble tray through a liquid-sealed downspout. Excess green acid was conducted from the bubble tray through a liquid-sealed overflow pipe, and was withdrawn from the bottom of the tower. The bubble caps and overflow pipes were constructed to permit a head of 0.25-inch of green-acid solution on the bubble tray. The tower was insulated with 2 inches of hair felt; and a glass panel extended 3 feet above the bubble plate, which permitted observation of the bubble-formation

stability, size, and other operation conditions. Provisions were made for the introduction of a second bubble plate between the lower plate and the bubble breaker, and gas-sampling tubes were provided near the base and near the top of the tower. The upper sampler was located above the foam breaker, and was protected

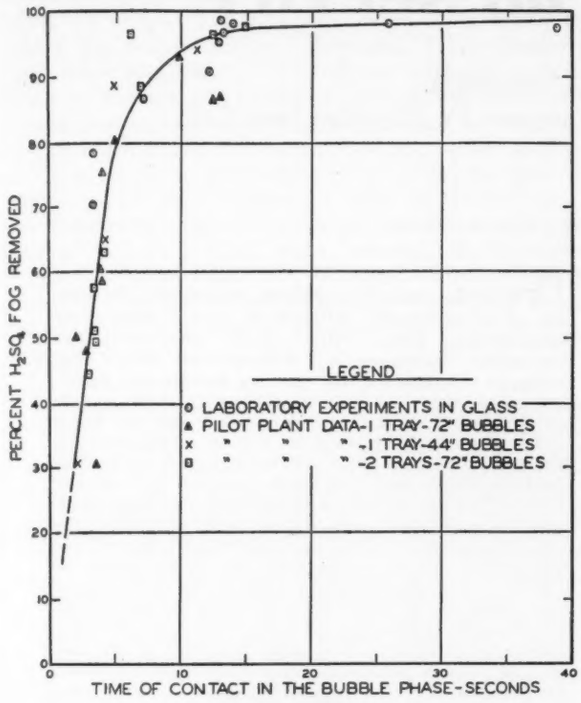

PERCENT H_2SO_4 FOG REMOVED
TIME OF CONTACT IN THE BUBBLE PHASE-SECONDS
LEGEND
LABORATORY EXPERIMENTS IN GLASS
PILOT PLANT DATA-1 TRAY-72" BUBBLES
" " " -1 TRAY-44" BUBBLES
" " " -2 TRAYS-72" BUBBLES

FIGURE 3
Correlation of Bubble-Phase Absorption Vs. Time of Contact for Laboratory and Pilot-Plant Data.

from entrained green acid in the effluent gas by a 2-inch layer of carbon raschig rings. Protection from atmospheric eddy currents was afforded by a 6-inch layer of 3-inch spiral ceramic rings. After equilibrium had been established during the test periods, sampling was carried out in the manner described for laboratory experiments, i.e., by drawing metered samples of gas from the lower and upper sample points through a train of moistened asbestos pads. Sampling was continuous over the duration of the test runs, which usually were from 1 to 2 hours.

The contact time between the H_2SO_4 mist and the bubble phase was calculated from gas velocities and the volume of the tower occupied by the bubble phase. The gas velocities were measured experimentally by determining the time required for an H_2S injection at the bottom of the tower to darken lead-acetate-saturated paper at the top of the sampling section. Velocities were adjusted at the beginning of each run by the proper selection of orifices or by varying the operation of the blowers, and were checked at the completion of each run. Very little variation was found during any given run. The maximum velocity rates, which permitted stable bubble formation, were found to be approximately 2.0 feet per second in this tower. At higher rates, the liquid seal was destroyed around the bubble caps, and the formation of a continuous bubble phase was impossible.

The pilot-plant data summarized in Table 5 may be divided into three groups of experiments. In tests A-1 through A-10, one bubble plate supported a 72-inch head of bubbles, and the only variable was the time of contact. In tests A-21 through A-24, a single bubble plate was used, but supported only 60 percent of the bubble height of the first group of experiments. Contact time was varied by changing the gas velocities over the range 1 to 10 feet per second. In tests A-12 to A-20, inclusive, 2 bubble plates were used supporting the full 72-inch head of bubbles.

These data clearly show that the time of contact between the acid mist and the bubble phase, and the gas velocity are controlling factors in the acid-absorption efficiency of this type of equipment.

The variation in the percent absorption with increasing time of contact, as shown in the first group of experiments, may be accounted for by slight errors in the measurement of contact time in which the order of accuracy was estimated to be ± 1.0 seconds. Thus, in the range of 0 to 8 seconds time of contact, the percent absorption increases very rapidly; and a displacement of 1 second, as shown in Figure 3, becomes a 15- to 20-percent difference in the amount of H_2SO_4 absorbed.

No increase in the effectiveness of absorption can be attributed to the use of two bubble plates, despite the fact that smaller-diameter bubbles were formed in the passage of the foam from the lower tray through the upper tray. The use of two trays doubled the pressure drop through the absorption system, but in practical usage might prove to be advantageous—by insuring bubble formation throughout the absorption system, and by aiding in the support of the bubble structure.

Laboratory and pilot-plant data are shown together in Figure 3, in which the time of contact in the bubble phase is plotted against the percent absorption of H_2SO_4.

Conclusions

Laboratory and pilot-plant data have demonstrated the high efficiency of H_2SO_4 removal by green-acid bubble-phase absorption. At 10 to 11 seconds time of contact, 93 to 95 percent of the total H_2SO_4 may be removed in equipment having a pressure drop of only approximately 2 inches of water. Economic calculations have indicated installation, operating, and repair costs to be approximately 50 percent those of equivalent electrical precipitation equipment.

Acknowledgment

The authors gratefully acknowledge the assistance and helpful criticisms given by Dr. A. B. Brown and R. B. Selund, R. C. Comings, and J. R. Stackhouse, both in the experimental work and in the preparation of this paper.

Bibliography

[1] *Disposal of Refinery Wastes*, Sect. II, American Petroleum Inst., New York (1938).
[2] W. E. Gibbs, *Clouds and Smokes*, 96, Blakiston, Philadelphia (1923).

Testing of Non-Ferrous Alloys for Condenser-Tube Service Simulating Actual Industrial Service

R. W. MOORE and S. KLEINHEKSEL
General Laboratories, Socony-Vacuum Oil Company, Inc., Brooklyn, New York

DUE to the varied conditions encountered in service, it is extremely difficult to devise laboratory experiments which will evaluate adequately the corrosion resistance of non-ferrous alloys for refinery condensers. By placing tensile-test specimens in the lines, in conjunction with small experimental condensers in parallel with the large condensers, it is believed that results indicative of those that may be expected in the larger units may be had. The method of mounting and placing the tensile specimens, and a description of the experimental condensers, are given. Data are shown in chart form; these data were obtained from tensile specimens placed in the lines. In order to be of value, these data must be obtained upon specimens placed in both the inlet and outlet of the condenser—inasmuch as it has been found that corrosive conditions are quite different at the two points, and both conditions must be taken into consideration in the evaluation of the alloys. Very little data have been obtained as yet upon the experimental condensers.

Some remarks are devoted to the study of conditions which affect condenser-tube life. Admiralty tubing, it has been found, is used in most non-ferrous condenser installations; and even under severe corrosive conditions it is quite satisfactory. It is pointed out, therefore, that attention to the study of conditions causing corrosion and means of remedying them would be of value.

This paper was presented to Division of Refining, before the Tenth Mid-Year Meeting of the American Petroleum Institute, at the Texas Hotel, Fort Worth, Texas, May 29, 1940.

THE selection of copper alloys best suited for tube service in condensers and exchangers is a problem of major importance to oil-refinery engineers. The conditions encountered in service are varied—the corrosive gases or liquids, the temperature and the velocity, often being different for each exchanger in the refinery. Purely laboratory experiments are of little value; for, even if they are designed carefully for a particular case, they cannot be expected to simulate exactly service conditions. On the other hand, refinery engineers usually cannot afford to experiment by building entire exchanger-tube bundles using new and untried alloys. Consequently, the logical and common procedure is to use a combination of the two methods in which test specimens judiciously are placed in the same liquid or gaseous stream flowing through the equipment being tested during actual service.

The above method for testing the corrosion resistance of copper alloys often has proved to be inaccurate because of the difficulty in properly interpreting the results of the test. It has been necessary mainly to depend upon visual inspection, inasmuch as the method involving the loss of weight of the specimen during the test is accurate only when corrosion is general and uniformly distributed over the entire specimen. Pitting, dezincification, and other types of localized corrosion will invalidate the results as determined by the weight-loss method. D. K. Crampton and N. W. Mitchell[1] have described a method for evaluating corrosion of test specimens by measuring the loss in tensile strength experienced by the specimens during the test. The method has been utilized in certain experiments involving tensile corrosion test strips, and has been adapted further to the evaluation of the corrosion resistance of condenser tubes under test in experimental condensers. Each of these methods will be described briefly.

Tensile Corrosion Test Specimens

The specimens used are strip tensile test specimens conforming to Figure 7 of *ASTM Standard Methods of Tension Testing of Metallic Materials (E 8-36)*.[2] They are 6 inches in length, 0.032-inch thick, and 0.75-inch wide, with a reduced section at the center 0.5-inch wide. A large number of these specimens are pulled in a tensile machine to determine the average tensile strength of the alloy under test. Similar specimens then are mounted in triplicate on test racks, and subjected to the corroding medium for a period of time such that the more resistant alloys in the group lose a measurable amount of their original tensile strength. These specimens then are pulled and the loss in tensile strength, as calculated on the basis of the cross-sectional area before corrosion, is taken as a measure of corrosion resistance.

The following are some of the reasons why tensile-strength losses are more satisfactory for estimating corrosion resistance of copper alloys than weight losses.

1. Damage to copper alloys by selective solution, of which dezincification is an example, by pitting or by intercrystalline corrosion may be very great, but may show no appreciable weight loss. Tensile-strength losses are much more nearly proportional to the actual damage done by these common types of corrosion.
2. The tensile-strength-loss method automatically selects the area on the specimen where the greatest damage by corrosion has occurred, thereby making it unnecessary to measure depth of pits, cracks, etc.
3. It is unnecessary to remove the corrosion products from the specimens before pulling, as the tensile strength of the former is insignificant. Thus large possible errors due to cleaning in the weight-loss method are eliminated.
4. Differences in density for the various alloys do not enter into tensile-strength-loss measurements as they do into weight-loss measurements.

Twenty different copper alloys in strip form, 0.75-inch wide and 0.032-inch thick, covering a wide range of composition, were supplied by four major brass companies. The strips, rolled from split condenser tubes, were received in quarter hard condition to facilitate cutting of the tensile specimens. Two hundred specimens of each alloy were die-punched from the strips, thus insuring perfect uniformity upon which the tensile method depends. After numbering, they were annealed in accordance with the specifications of the manufacturer of each alloy. This served to remove strains in the metal caused by cold work in the rolling and die-punching operation, and gave to each metal a microstructure similar to that ordinarily found in a condenser tube of that alloy. The microstructure and the average hardness and tensile strength of each alloy were determined. In order to obtain a value for the original tensile strength, numerous specimens of each alloy were pulled. In no instance did the tensile strength as determined for one specimen deviate more than 2.5 percent from the

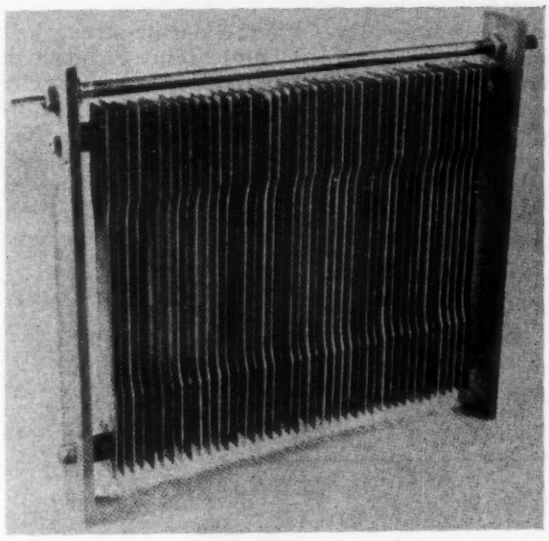


FIGURE 1
Grid Type of Test Rack

mean tensile strength of the alloy. The average deviation from the mean tensile strength of each alloy was approximately 1 percent. This excellent uniformity of the specimens made it unnecessary to determine the dimensions of individual specimens.

Two types of test racks have been found convenient. In the grid type, triplicate specimens of 14 different alloys are mounted in a line on a brass frame, the specimens being separated by ⅛-inch bakelite or glass spacers. The overall dimensions of the rack are about 1 inch by 7 inches by 8 inches, and the rack may be suspended conveniently in cooling boxes, vapor chambers, etc. In the second type the tensile specimens are supported lengthwise in a pipe nipple 6 inches long. Triplicate specimens of 8 different alloys may be placed in a nipple 4 inches in diameter, and triplicate specimens of 14 different alloys in a nipple 6 inches in diameter. In each instance the cross-sectional area of the pipe is reduced about 15 percent by the presence of the specimens and their support. The nipple containing the tensile specimens, when fitted with flanges, may be placed in series with condensers or exchangers at both inlet and outlet—thus insuring test conditions nearly identical to those encountered in actual operation. This method has an added advantage in that erosion losses by impingement may be measured simultaneously with the attack by corrosion. The types of

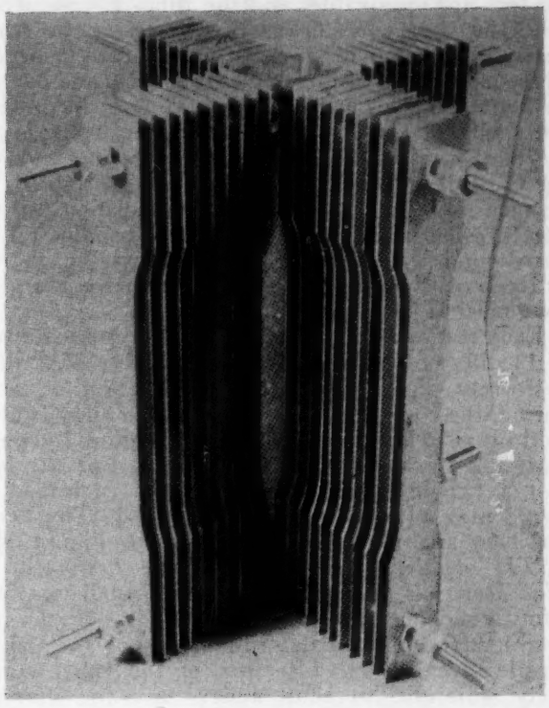


FIGURE 2
Test Rack Suitable for Placing in Pipe Line or Nipple

test racks and method of installation are shown in Figures 1, 2, and 3.

Experimental Condensers

The better alloys of the group for a given service, as determined by the tensile corrosion strip test,

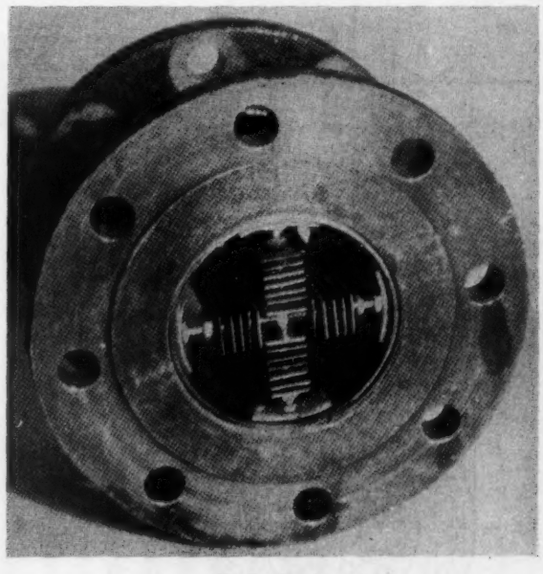


FIGURE 3
Test Rack Installed in Flanged Nipple

may be tested further in a relatively inexpensive manner by use of experimental condensers. We are indebted to the American Brass Company for the essentials of the design of these condensers. A de-

tailed drawing is shown in Figure 4. It consists of a steel shell 8 inches ID, fitted with naval bronze tube sheets drilled and tapped to support 24 condenser tubes 5/8-inch OD and 5 feet long. The steel headers are removable, and the tubes are secured in the tube sheets by means of ferrules—thus readily permitting removal of the tubes for inspection. The condenser is of the single-pass type, and contains no baffles. Both headers and the inlet and outlet to the shell are fitted with thermometer wells so that the temperatures of the materials entering and leaving the tubes and the shell may be determined. Adjustment of the valves permits regulation of temperatures which may be made approximately to correspond with those of the industrial exchanger, or bank of exchangers, with which the experimental condenser is in parallel.

Each condenser may be tubed with duplicate tubes of 12 different alloys, or triplicate tubes of 8 alloys, uniformly distributed. Upon completion of a test period, the corrosion resistance of each alloy is evaluated by visual and microscopic inspection, by weight loss, and by loss in tensile strength. For the latter test a tensile specimen is cut from each end and the center of each tube, and pulled. The tensile specimen and metal plugs conform to Figure 11 of *ASTM Standard Methods of Tension Testing of Metallic Materials (E-8-36)*.[3] Tubes for installation in the 5-foot condenser are ordered in 7-foot lengths, thus permitting duplicate determinations of the original tensile strength on a section of the tube immediately adjacent to that under test for corrosion resistance.

Evaluation of Copper Alloys for Condenser Tubes by Tensile Corrosion Test Strips

The practice in these cases is to place test racks supporting tensile corrosion specimens in the inlet and outlet of a given exchanger during the actual operation of the unit.

The data obtained to date have not been extensive, and those available are shown hereinafter:

Partial Condenser of an M. W. Kellogg Atmospheric Pipe Still

a. The cooling medium is East Texas crude, in that 60° F. and out at 168° F.

b. The shell side of the condenser partially condenses light naphtha gas, and steam; the inlet temperature is 220° F. and the outlet 180° F.

c. Sufficient ammonia gas is introduced into the bubble tower, preceding the partial condenser, to maintain a pH* of 7.5 in the water separating from the naphtha.

d. Two grid-type racks supporting triplicate tensile test specimens of 14 different alloys were placed in the vapor chamber at 220° F. preceding the condenser, and another was located in a cast-iron manifold carrying liquids from the partial condenser to the cooling boxes.

The average values for the tensile-strength losses due to corrosion are shown in Figure 5. Inspection of Figure 5 indicates that corrosion is quite extensive for all of the alloys tested, and that no one alloy has an appreciably greater resistance toward the type of corrosion encountered here than the remaining alloys. The active corrosive agents known to be present are sulfides and ammonia. The results of the tests indicate, therefore, that it would be doubtful

* Hydrogen-ion concentration.

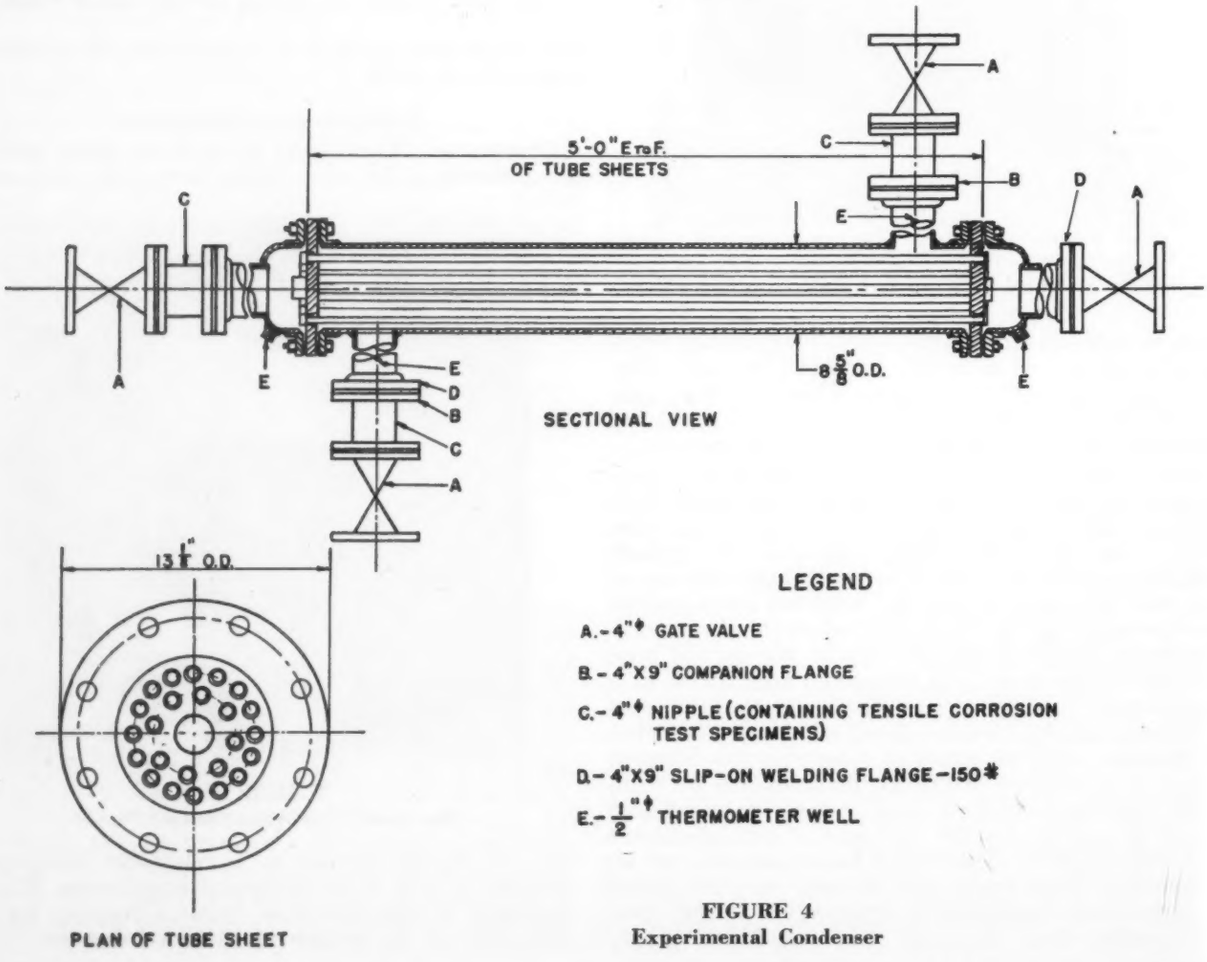


FIGURE 4
Experimental Condenser

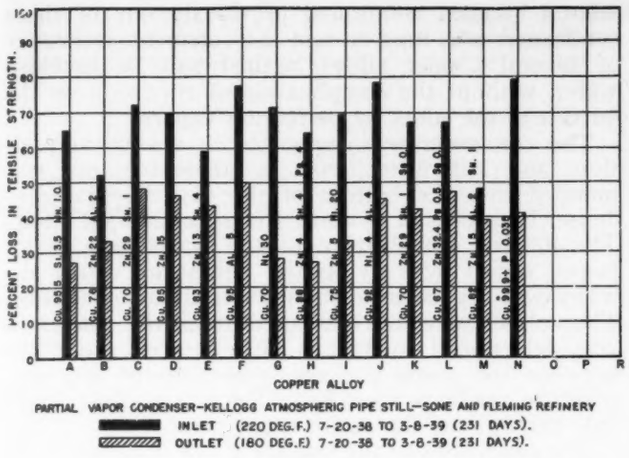

PERCENT LOSS IN TENSILE STRENGTH.
COPPER ALLOY
PARTIAL VAPOR CONDENSER-KELLOGG ATMOSPHERIC PIPE STILL-SONE AND FLEMING REFINERY
INLET (220 DEG. F.) 7-20-38 TO 3-8-39 (231 DAYS).
OUTLET (180 DEG. F.) 7-20-38 TO 3-8-39 (231 DAYS).

FIGURE 5
Tensile Corrosion Test Specimens

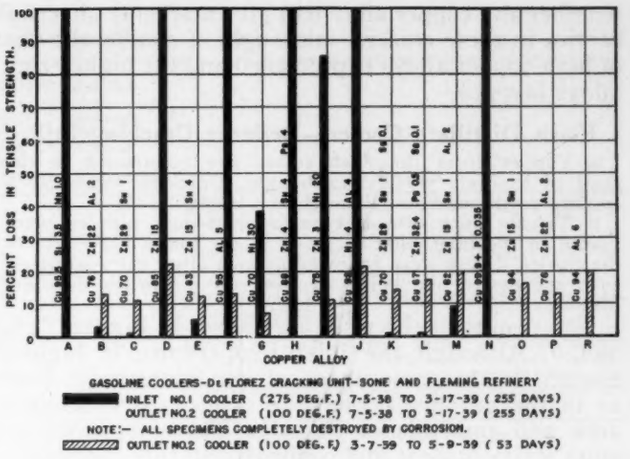

PERCENT LOSS IN TENSILE STRENGTH.
COPPER ALLOY
GASOLINE COOLERS-DE FLOREZ CRACKING UNIT-SONE AND FLEMING REFINERY
INLET NO.1 COOLER (275 DEG. F.) 7-5-38 TO 3-17-39 (255 DAYS)
OUTLET NO.2 COOLER (100 DEG. F.) 7-5-38 TO 3-17-39 (255 DAYS)
NOTE:- ALL SPECIMENS COMPLETELY DESTROYED BY CORROSION.
OUTLET NO.2 COOLER (100 DEG. F.) 3-7-39 TO 5-9-39 (53 DAYS)

FIGURE 6
Tensile Corrosion Test Specimens

if the tube life in this condenser can be increased appreciably by the selection of any given copper alloy. The use of a relatively inexpensive alloy such as admiralty, therefore, is indicated with the possibility of longer tube life being obtainable by proper changes, of a chemical nature in the operating conditions.

The record of tube-bundle lives in this condenser to date is as follows:

MATERIAL	Gage (Birmingham Wire)	Life (Months)
Admiralty	14	20
Steel	16	9
Nickel-aluminum bronze	16	24½
Antimonial admiralty	16	14¾
Copper nickel (80-20)	16	17 months to 4/1/40

Gasoline Coolers—Deflorez Cracking Still

a. Three vertical coolers in series cool cracked gasoline from Mirando crude from 275 to 75° F. Brackish water is the cooling medium.

b. Lime was added to the crude before the crude entered the furnace.

c. Test racks supporting triplicate tensile corrosion specimens were placed in 6-inch nipples in the gasoline inlet to No. 1 cooler (275° F.) and in the outlet of No. 2 cooler (100° F.) for 255 days, the latter being corroded completely during the test period. A second test rack was inserted in the outlet of No. 2 cooler for 53 days.

Average values for tensile-strength losses due to corrosion for these two tests are shown in Figure 6, in which the exposure time for the inlet is approximately five times that of the outlet. Regarding the inlet specimens, it will be noted that a large variation in corrosion resistance exists among the various alloys tested. Those alloys containing 85 percent or more copper show very poor corrosion resistance. Excellent resistance is noted for lower copper content and intermediate or high-zinc alloys. Copper nickel appears to have an itermediate corrosion resistance. In the case of the outlet specimens, all alloys show appreciable corrosion—with only minor variations, regardless of composition.

Although no ammonia was introduced into the unit, it was known to be present in considerable quantities as evidenced by the deposits of ammonium chloride in the coolers and on the test specimens. Water separating in the coolers is acidic, and sulfides are present also in the gasoline in considerable amounts. It appears, therefore, that at the higher inlet temperature the effect of ammonia is minimized and sulfide corrosion predominates, thus favoring corrosion of the high-copper alloys; whereas the intermediate or high-zinc alloys show good resistance. At the lower outlet temperatures, the combination of ammonia, sulfide, and acid corrosion causes all of the copper alloys tested to corrode rapidly, regardless of composition. It is doubtful, therefore,

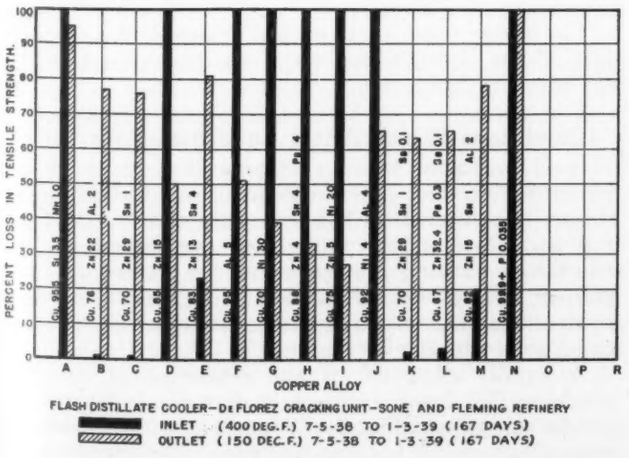

PERCENT LOSS IN TENSILE STRENGTH.
COPPER ALLOY
FLASH DISTILLATE COOLER-DE FLOREZ CRACKING UNIT-SONE AND FLEMING REFINERY
INLET (400 DEG. F.) 7-5-38 TO 1-3-39 (167 DAYS)
OUTLET (150 DEG. F.) 7-5-38 TO 1-3-39 (167 DAYS)

FIGURE 7
Tensile Corrosion Test Specimens

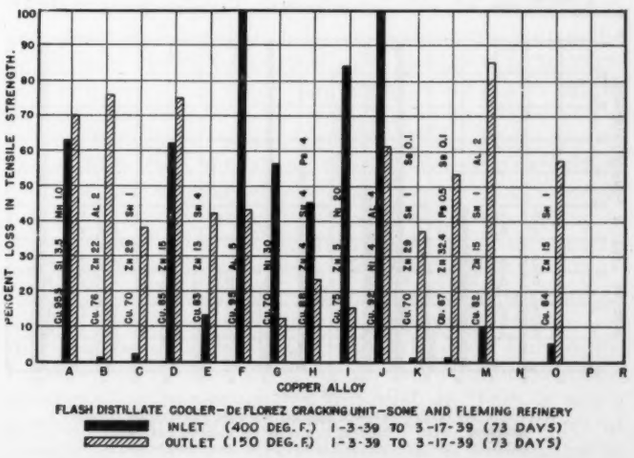

PERCENT LOSS IN TENSILE STRENGTH.
COPPER ALLOY
FLASH DISTILLATE COOLER-DE FLOREZ CRACKING UNIT-SONE AND FLEMING REFINERY
INLET (400 DEG. F.) 1-3-39 TO 3-17-39 (73 DAYS)
OUTLET (150 DEG. F.) 1-3-39 TO 3-17-39 (73 DAYS)

FIGURE 8
Tensile Corrosion Test Specimens

whether any copper alloy will give markedly superior service in these coolers—although, of course, the use of high-copper alloys is precluded and the higher-zinc alloys favored.

Flash Distillate Cooler—Deflorez Cracking Still

a. Vapors from the flash tower are condensed in the shell of a single vertical exchanger. Brackish water, as a cooling medium, flows through the tubes.

b. Tensile corrosion test racks in 6-inch nipples were placed in the inlet (400° F.) and in the outlet (150° F.) of the cooler. These were followed by two other installations—each successive one being exposed for a shorter duration of time.

The results of the tests are shown in Figures 7, 8, and 9. Although the inlet temperature is higher, essentially the same chemical conditions exist here as in the gasoline coolers, ie., sulfide, hydrochloric acid, and ammonia or its salts. There is, however, more water present and condensed in this condenser, which may account for the fact that only traces of ammonia were found in the corrosion products on the specimens. The soluble copper-ammonium complex readily is washed away by the water, leaving the insoluble sulfides.

As in the case of the gasoline coolers, inspection of the charts shows that the high-copper alloys are least resistant toward corrosion at the higher temperatures of the inlet, where the effects of acid and sulfide may be expected to be most severe. The nickel alloys also are attacked badly at the inlet, whereas the alloys having intermediate or high zinc content show excellent resistance. At the lower temperatures of the outlet, again the difference in the corrosion resistance of the various alloys is much less pronounced due to the numerous types of corrosion exhibited. The copper-nickel alloys appear to be most resistant under the outlet conditions; but it is doubtful that in actual service, in this condenser, they would prove more resistant than the less expensive alloys such as admiralty or aluminum brass.

Evaluation of Copper-Base Alloys for Condenser-Tube Service by Means of the Experimental Condenser

Four of these units have been installed in parallel, with large exchanger bundles, on various units at different plants in the East. At the present time these experimental units have not been on stream for a sufficiently long period of time to yield any data for evaluation.

Previous to the installation of the four experimental bundles mentioned previously one of these condensers was used to test the corrosion resistance of several copper alloys against salt or brackish water, without the complication of corrosion on the outside of the tubes by petroleum vapors.

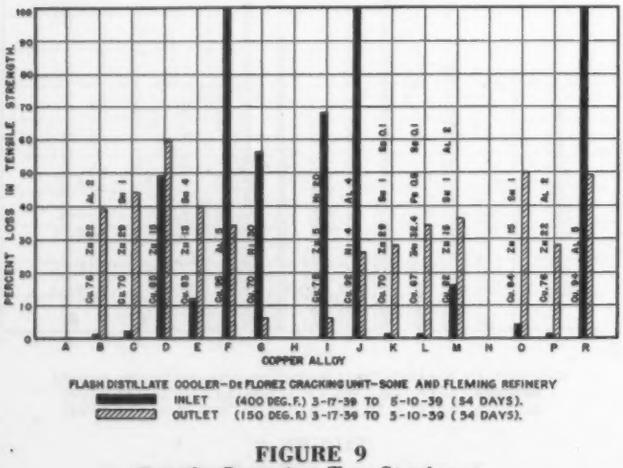

PERCENT LOSS IN TENSILE STRENGTH
COPPER ALLOY
A B C D E F G H I J K L M N O P R
FLASH DISTILLATE COOLER—DE FLOREZ CRACKING UNIT—SONE AND FLEMING REFINERY
INLET (400 DEG. F.) 3-17-39 TO 5-10-39 (54 DAYS).
OUTLET (150 DEG. F.) 3-17-39 TO 5-10-39 (54 DAYS).

FIGURE 9
Tensile Corrosion Test Specimens

The condenser was supported in a vertical position, and hot water from a condenser box was pumped into the bottom of the experimental condenser by means of a steam-driven centrifugal pump. The desired temperature of the water was maintained easily by varying the height at which the water was tapped from the industrial condenser box. The volume of water flowing through the condenser was determined by means of a meter in the line between the pump and condenser; meter and temperature readings were recorded at two-hour intervals throughout the entire experiment.

The conditions of the test are given in detail in the following items:

1. *Alloys:* Duplicate tubes of eight different copper alloys were used. The weight of each tube was recorded before installation.

2. *Water:* The water used in this experiment was a brackish or salt water from Newtown Creek in Brooklyn—which is used for cooling purposes at the refinery located there. A typical analysis of this water follows:

	Parts Per Million
pH	7.2
Chlorides as NaCl	14,925
Sulfates as Na_2SO_4	1,923
Calcium as CaO	350
Magnesium as MgO	923
Organic matter	2,370
Total solids	19,710

3. *Temperature:* The temperature of the water in the tubes of the experimental condenser was maintained at 135° F.± 5° F. This is from 20 to 25° F. higher than the highest design temperature used on the industrial units at this refinery and, therefore, is an accelerated condition with respect to temperature.

4. *Velocity:* The flow through the experimental condenser was maintained at 65 gallons per minute, which corresponds to a water velocity in the tubes of approximately 6 feet per second. This velocity also represents an accelerated condition, as velocities of 1.5 to 2.5 feet per second are used for design purposes for industrial units at this refinery.

5. *Duration of test:* The condenser tubes were in service under the above conditions during 24-hour days for a total of 266 days.

6. *Cleaning of tubes:* After the test period, and prior to weighing, the tubes were cleaned by turbining with a brass wire brush. All of the corrosion product was not removed by this treatment, a thin scale-like deposit remaining in most cases. After weighing, the tubes were sectioned lengthwise to permit inspection. Also a section of each tube was cleaned chemically in a 1 : 1 HCl solution in accordance with the procedure recommended by the American Society for Testing Materials, and a microscopic examination was made of the cleaned surface in each instance.

The alloys used, their weight losses, and a description of the deposit and metal surface after the test are given in Table 1.

Conditions Which Affect Condenser-Tube Life

It is probably safe to assume that most of the effort which has been expended in studying condenser-tube corrosion has been directed toward finding an alloy which will resist the complexity of conditions causing the corrosion. As pertinent to the subject, it might be advisable to direct a few remarks toward that phase which has to do with the study of conditions causing corrosion.

A survey of most of the refineries of Socony-Vacuum Oil Company reveals that admiralty tubing comprises approximately 88 percent of the non-ferrous alloys used for this purpose. The survey also shows that most condenser-tube failures have occurred from the vapor or petroleum side of the tubes.

TABLE 1
Brackish Water Vs. Copper Alloys

Name of Alloy	COMPOSITION				WEIGHT LOSSES		REMARKS
	Copper	Zinc	Tin	Others	Average Weight Loss of Tubes (Grams)	Average Weight Loss of Tubes (Percent)	
Aluminum brass	76	22	..	Al-2	18	2.4	Mild general dezincification and minor pitting. Deposit, thin tenacious carbonate film.
Super nickel	70	..	..	Ni-30	192	23.8	General thinning with only minor pitting. Flaky carbonate deposit.
Barronia	83	13	4	.....	68	8.4	Slight thinning and mild dezincified patches. Thin tenacious carbonate film.
Admiralty	70	29	1	.....	54	7.0	General thinning and mild pitting. Tendency toward plug dezincification. Thick black carbonate deposit.
Nickel-aluminum bronze	92	Ni-4 Al-4	22	2.8	..	....	General thinning and rather severe pitting—copper deposited in pits. Hard thin carbonate film.
Red brass	85	15	..	.....	96	12.3	Severe thinning, mild pitting and dezincification. Thick, bulky carbonate deposit.
Ad aluminum	82	15	1	Al-2	30	4.0	Mild dezincified areas. Thick tenacious carbonate deposit.
Ambronze	83	13	4	.....	92	12.0	Mild thinning and dezincified areas. Minor pitting. Tenacious thin film.

Temperature of water, 135 °F. ± 5 °F. Velocity through tubes, 6 feet per second. Duration of test, 266 days.

It would seem, therefore, inasmuch as admiralty metal is the most universally used alloy for refinery condenser service, and the other copper-base alloys do not seem to have a sufficiently better corrosion resistance, that it would be advisable to devote some attention to the conditions causing the corrosion and to a study of ways and means of altering them so that the corrosion is prevented or diminished.

The examination of condenser bundles which have failed reveals certain conditions, among which the following may be mentioned. Part of the bundle may be dry, usually near the inlet where the temperature has been high. The corrosion product may be large or small, flaky or tenacious, hard or soft—color ranging from white (ammonium chloride) through red, gray, brown, black, blue, or green. Cases have been noted when a white encrustation of ammonium chloride has occurred and no ammonia has been added to the system. Other parts of the bundle may be moist or wet with both water and petroleum products. Accumulations of corrosion product may be large and lodged in the bottom, between tubes, or behind baffle plates. It may be composed of organic matter, flakes of copper sulfide or oxide, and iron oxide. The corrosion may be localized or general throughout the bundle. The tubes may be pitted or show a general thinning of the wall until they have corroded through.

Examination of the water which oftentimes can be drawn off the bottom of a condenser may reveal the presence of one constituent of the copper alloy and not the others. Ammonia, iron, chlorides, sulfates, and other radicals may be present. The iron may be dissolved in the form of ferrous salts, giving the water a perfectly clear or colorless appearance instead of the usual red or yellow color or suspension, accompanying iron corrosion. Ammonia may be present, although it has not been added to the system. Sulfides may not be present, but this does not indicate their absence, as they may be found in the corrosion product and in the gases. The pH or acidity of the water may range from 3.0 to above 7.0—depending upon whether neutralizers are added. Hydrochloric and organic acids of low molecular weight, such as acetic acid, may be identified. Organic compounds, with odors resembling phenols and amines, may be isolated. Some of the salts formed in the corrosion process may be of a complex nature; and although their formation in one part of the condenser may result in a soluble form, as they come into another part of the condenser—meeting condensed water, boiling conditions, contact with various acidic constituents—they may break down or be precipitated, or may change their form and be removed by the water.

Oftentimes the design of the bundle is a factor. Some condensers, especially vertical ones, may have the outlet 2 feet or 3 feet above the bottom of the bundle, or the outlet pipe may take the form of a **U**-trap. These conditions cause an accumulation of liquid, usually water, in the bottom of the bundle. This liquid, together with the accumulation of corrosion product, produces a stagnant condition which may be very favorable to corrosion. Provision for proper drainage or water separation is advisable. Steel baffle plates are used in many condensers, and tube failures have been observed to take place by pitting at or near these baffles. Under these conditions the steel is anodic to the copper alloy, and corrodes rapidly while the tube is protected. This galvanic action produces a large quantity of iron-corrosion product, which may lodge or collect at the baffle. An accumulation of water and salts beneath this corrosion product may be very corrosive to the tubes due to the formation of a so-called concentration cell. It would seem that brass baffle plates might be advantageous.

The foregoing points indicate the complexity of the situation. They show that a simple analysis of one corrosion product removed from the condenser bundle is of but little value, and also that the complete answer may not be found always in the search for a suitable alloy to resist the corrosion.

It might be emphasized, as one of the salient points of the discussion, that more intensive attention and investigation to be given to a study of the conditions which cause the corrosion, and to modifications of operation to prevent or diminish it. This is not a simple nor an easy problem. To study the effect of corrosive conditions upon various alloys is similar to following the course of least resistance. It is an

[*Continued on page 88*]

Cathodic Protection of Condensers and Coolers Utilizing Brackish Bay Water

By W. A. S. WRIGHT and J. H. BROOKS
Union Oil Company of California, Los Angeles

RAPID failure had occurred in red-brass tubes installed in a surface condenser operating on brackish bay water. These failures were attributed to deposit attack caused by the entrance of foreign material into the tubes.

The red-brass tubes were replaced with admiralty metal, and a system of cathodic protection installed based on an impressed current of 2.5 amperes per 1000 square feet of tube surface. Some minor pitting of the tube ends has occurred since cathodic protection was applied; but, after 14 months of service, no failures have occurred, and no serious depreciation has been reported.

Cathodic protection has been applied also to additional refinery cooling equipment, and during 16 months of service no failures of tubes have occurred.

This paper was presented to Division of Refining, before the Tenth Mid-Year Meeting of the American Petroleum Institute, at the Texas Hotel, Fort Worth, Texas, May 29, 1940.

THE cathodic protection of condensers is not a new development, as it has been employed by various power plants for about 30 years; but it is only compartively recently that this system of protection has been extended to refinery equipment. In view of this fact it may be of interest to discuss briefly the protection of a horizontal two-pass divided water-box condenser located in a refinery on San Pablo Bay near San Francisco, California.

In this condenser brackish bay water is used for condensing, under vacuum, exhaust steam from the pumps servicing a cracking unit. Under average operating conditions the salt-water inlet temperature is 55° F., whereas the outlet temperature of the condensate is 95 to 100° F. The rated capacity of this condenser, which has a tube area of 2800 square feet, is 40,000 pounds of steam condensed per hour, with a water circulation of 2450 gallons per minute.

The tubes are approximately 16 feet long and, at the inlet end of each pass, are rolled into the tube sheet and flared; whereas at the outlet end the tubes are packed with metallic packing (without ferrules). The tube sheets are of Muntz metal; whereas the shell, water boxes, water-box cover plates, and hot well are constructed of gray iron. In this condenser salt water flows through the tubes, and steam flows around the tubes through the shell.

Early Tube Failures

The red-brass tubes originally installed were not given cathodic protection, and failed rapidly. The chemical analysis, grain size, and physical properties of the tubes were normal for this class of material. The first tube failures were reported after six months' service; whereas within one year about half the tubes had developed leaks, and most of the remaining tubes were pitted severely. The majority of failures occurred in the first pass tubes located in the corners formed by the horizontal and vertical water-box division plates. Other failures were scattered throughout the first and second passes.

The tubes showed no appreciable corrosion of the outside surfaces, but the inside surfaces were covered with a light deposit of sediment and corrosion product, beneath which there was evidence of mild erosion. There were also numerous small pitted areas along the tube surface and, in addition, several regions where intense localized pitting had penetrated the tube wall. Associated with the latter were loose spongy deposits of copper, which are indications of dezincification, and, in addition, small deposits of sand and debris. The severe pitting of the interior surface of these tubes was believed due to deposit attack, a form of localized corrosion caused by oxygen-concentration cells. Ordinarily, in this form of attack, areas shielded by foreign bodies become anodic with respect to surrounding areas, due to a reduction of the oxygen content.

After the various phases of this corrosion problem had been investigated, it was decided to replace all of the tubes in this condenser with admiralty metal. Screens also were provided to prevent foreign materials from being carried into the tubes, and a more rigid inspection and cleaning program was initiated. In addition, cathodic protection was applied to the entire condenser in order to prevent, insofar as possible, further corrosion.

It is well-recognized that slight dissimilarities in metals, or in surface conditions of the tubes, set up galvanic action with the salt water as the electrolyte—resulting in the solution of the zinc and the subsequent deposition of copper as a spongy mass. This attack on the metal can be minimized if the potential of the water is raised to a point sufficiently higher than the potential of the galvanic couple, by the introduction of an external source of potential.

It is possible to increase the potential of the water with reference to the tubes and tube sheets by the installation of cast-iron electrodes in water boxes. These electrodes are insulated from the frame of the condenser and connected to the positive terminal of a direct-current source, with the negative terminal connected to the tube sheets.

Details of Protective System

The general arrangement of this protective system is shown in Figures 1 and 2. One anode was installed

in each door; thus four anodes connected externally by a bus bar were required for each end of the condenser. The cast-iron anodes are approximately 2.5 inches thick, and have sufficient area for good current distribution over the tube sheet. It has been found that a spacing of from 3 to 4 inches from the tube sheet represents the best compromise between uniform current distribution, minimum resistance to water circulation, and satisfactory conductivity.

The spacing of the anodes is shown in Figure 3, This type of construction is sufficiently rigid, and permits ready renewal of any or all parts of the anode assembly for inspection or replacement.

The staybolt nuts were a problem, as they projected 2⅞ inches from the face of the tube sheet, and would have a tendency to increase the current considerably—making it necessary to insulate the nuts. This problem was solved by taping the nuts with rubber tape followed by friction tape, and then painting them with lacquer. The surfaces of the nuts

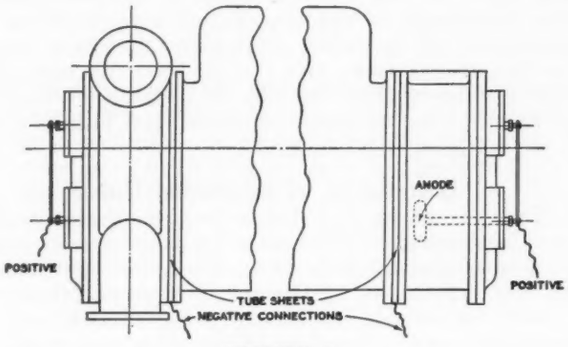


FIGURE 1
System of Cathodic Protection for Exhaust-Steam Condenser—Elevation

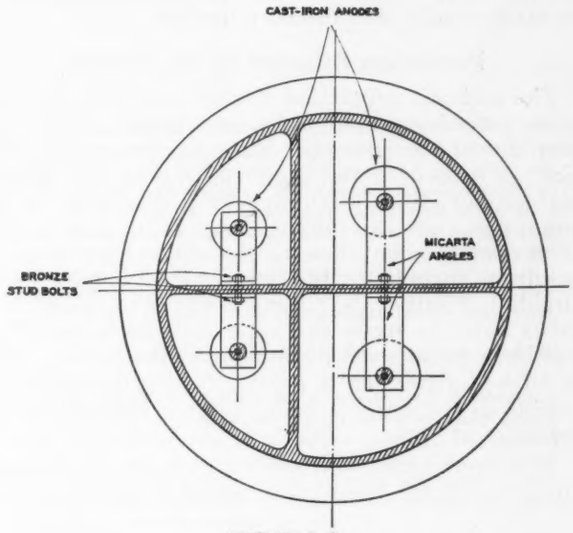


FIGURE 3
Details of Assembly—End View

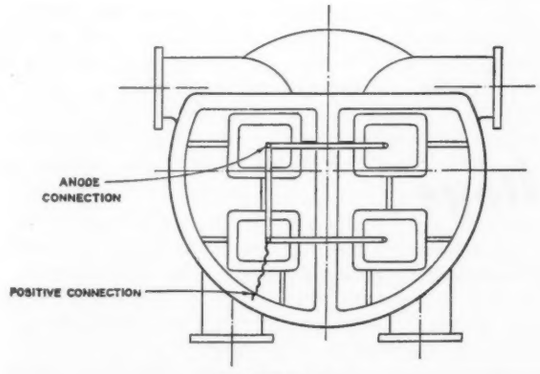


FIGURE 2
System of Cathodic Protection for Exhaust-Steam Condenser—End View

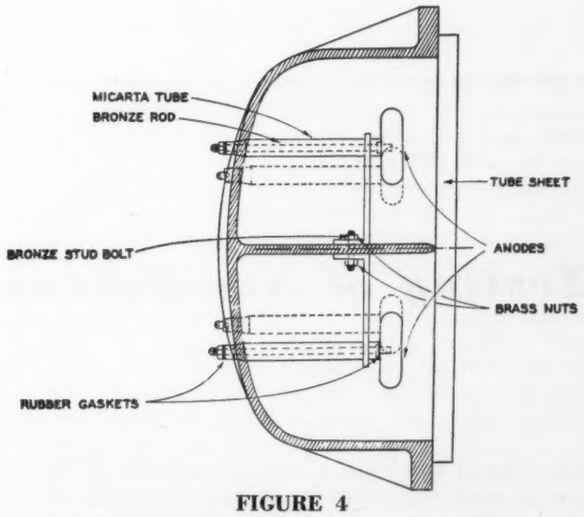


FIGURE 4
Details of Assembly—Sectional View

together with the Micarta supporting angles used for attachment to the condenser head. Details of construction are shown in Figure 4. The cast-iron anode is threaded to a bronze rod, which is protected from current leakage by means of a canvas-reinforced Micarta sleeve. The leakage of water is prevented by the installation of rubber gaskets between the sleeve and the anode, and between the sleeve and the exterior washer and nut. The Micarta sleeve is threaded into the shell, using a tapered pipe thread. were covered completely on both the front and sides to prevent current leakage to the nuts. This protection system was used because it eliminated the necessity of molding suitable rubber caps.

Operating Conditions

Preliminary tests were made with a battery in order to obtain the data necessary for the installation of the proper type of rectifier. In this preliminary test, it was found that a voltage of 4½ volts was

required to pass 7 amperes through the circuit, which is based on 2½ amperes per 1000 square feet of surface. A copper-oxide rectifier, having a variable-current range from 0 to 10 amperes and a direct-current voltage of 5 to 10 volts, was used; because this range was considered ample to allow for changes in resistance due to variable salt-water concentrations, temperature fluctuations, and variations of scale deposits on the electrodes and in the tubes.

The cast-iron electrodes are decomposed at an average rate of 0.1 ounce per operating hour, or about 35 pounds per ampere-year; and they were installed, therefore, in such a manner that replacement could be made readily at shutdown periods.

Protection Afforded by the System

The cathodic protection of this condenser has been in service about 14 months, and to date there have been no tube failures; but there has been mild corrosion as evidenced by slight pitting of the internal surface, which is developing at a slow rate. It was suggested that this pitting may be due to spacing of the anodes too close to the tube sheet, with the resulting turbulence liberating air dissolved in the circulating salt water; but careful inspection of the tubes failed to verify this type of depreciation. There has been some scale deposition in the tubes—which is advantageous, as it has an insulating effect, and results in the current being carried further into the tubes.

It is recognized that several changes in operating conditions have been made simultaneously, and the relative effect of each on service life is unknown. These changes were:

1. Substitution of admiralty tubes for red brass.
2. Installation of cathodic-protection equipment.
3. Use of strainers in salt-water line.
4. More rigid inspection and cleaning program.

There is evidence that the screening in the circulating line has not been entirely effective; for, at the time of a recent inspection, some mussels and other marine growth were found lodged in the water boxes and in the tubes themselves.

It is known that the combination of changes has prolonged the tube life, but it is difficult to state just how much of this increase is due to cathodic protection. Inasmuch as this installation was made for the protection of operating equipment, and not merely for the development of scientific data, no consideration has been given to the elimination of cathodic protection just to determine how soon failure would occur without this protection.

Installation of Additional Units

Cathodic protection has been applied also to four new fresh-water coolers, tubed with admiralty metal, and operating on salt water from the same source. In this particular equipment it was practicable to install the anodes in one end only—which was unfortunate, as the complete elimination of corrosion is dependent upon the current reaching all parts of the surface requiring protection which, even under the best conditions, is difficult to accomplish in the case of long tubes. These coolers have been in service for more than 16 months, and no tube failures have been reported.

Testing of Non-Ferrous Alloys

[*Continued from page 85*]

easy matter to retube a bundle and note its life. It is not an easy matter to know what is going on under the conditions to which the bundle is being subjected. It is still more difficult to change these conditions because it may necessitate changes in design and piping or delay in operation, as well as some apprehension as to whether proposed changes will be too costly or interfere with the quality of the product.

Among some of the things being tried are: cold-water deaeration to reduce the oxygen content of the water to approximately zero, when it is anticipated that much greater life will result; the use of chromates; and cathodic protection.[4] Some of our refineries have attained a large measure of success by the introduction of fresh water into the vapor stream, before it enters the condenser. This has been primarily to reduce the accumulation of ammonium chloride, but an additional benefit in the cleanliness of the bundle and longer life has resulted. There is also the possibility that the incorporation of neutralizers or corrosion-inhibiting chemicals in the added fresh water may be feasible. Benefit has been derived also from changes made in the piping, so that more adequate drainage of water from the condenser has resulted.

Bibliography

[1] *ASTM Symposium on Corrosion Testing Procedures,* 74 (1937).
[2] *Book of ASTM Standards,* Part I, 838 (1936).
[3] *Book of ASTM Standards,* Part I, 841 (1936).
[4] E. S. Dixon, "Service and Life of Non-ferrous Tubes in Petroleum Refining," *ASTM Bull. No. 102,* 21-6, Jan. (1940).

Significance of the Doctor Test for Gasoline

By JOHN HAPPEL and S. P. CAULEY
General Laboratories, Socony-Vacuum Oil Company, Inc., Brooklyn, New York

A CRITICAL review is presented covering the significance, to both consumer and manufacturer, of the doctor test as a gasoline specification. From the viewpoint of the former, the question of odor frequently is associated with this test. Data presented indicate that the test does not give a true indication of acceptable gasoline odor; and that the practical limit of mercaptan concentration in a gasoline, without causing objectionable odor, is usually much greater than that demanded by the sensitivity of the test.

It is concluded that, for the best interests of all concerned, the mercaptan concentration in a finished gasoline should be a matter of economics, and should not be fixed by an arbitrary test giving no real indication of gasoline quality. Its limited general use by agencies other than the refiners themselves, together with its lack of significance, should aid in the elimination of the doctor test as a gasoline specification.

This paper was Presented to Division of Refining, before the Tenth Mid-Year Meeting of the American Petroleum Institute, at the Texas Hotel, Fort Worth, Texas, May 30, 1940.

IT IS estimated that approximately six million dollars per year is spent by the petroleum industry to sweeten gasoline, assuming an approximate cost of 1 cent per barrel. This figure does not include the cost of losses in octane number and lead susceptibility, which result in many cases. It is apparent, therefore, that a critical examination of the significance of the doctor test should be made to determine whether an expenditure of this magnitude is justified. The purpose of this paper is to assemble such data as are at present available on this subject, and to point out the increasing inadequacy of this test as a significant item in gasoline specifications. The doctor test is essentially a sensitive test for mercaptans and/or hydrogen sulfide. Probably the most widely used procedure in this country for making the test is that known as the U. S. Bureau of Mines method.[1] Briefly, the test consists of shaking the naphtha under test with a solution of sodium plumbite, made by dissolving litharge in caustic soda. After the solution has been shaken vigorously, a pinch of sulfur is added, and the mixture is shaken again. If the sample is discolored or the yellow color of the sulfur film is changed noticeably or masked, the sample generally is reported as sour; but if it remains unchanged in color and the sulfur film is bright yellow or only very slightly discolored with gray or flecked with black, the sample is reported as sweet. Practically none of the commercial gasolines marketed at the present time contains hydrogen sulfide—which, if present, would form a black precipitate before the sulfur had been added, and would mask any precipitate formed later due to mercaptans.

The sensitivity of the doctor test in detecting mercaptans recently has been studied exhaustively by L. M. Henderson.[2] His data and that of other investigators—including experiments performed by the authors—indicate that the doctor test is sensitive to at least 0.001 percent by weight of mercaptan sulfur for mercaptans ranging from methyl to heptyl mercaptan. As mercaptans of a given molecular weight generally have a boiling point approximately equal to that of the hydrocarbon having 3 more carbon atoms per molecule, it is apparent that this sensitivity applies to the range of mercaptans normally encountered in gasoline.

History

The doctor test has been used for a long time by the petroleum industry, originating as a control test on the doctor-sweetening process. It first received prominence near the end of the World War, when it was used in aviation-gasoline specifications, and was adopted in 1918[3] by the U. S. Committee on Standardization of Petroleum Specifications. The adoption of this test was part of a general program for the elimination of extreme variations in the characteristics of gasolines which then were being distributed.[4] Use of the doctor test prevented the sale of gasolines containing mercaptans, which compounds were known to have objectionable odors and were believed liable to cause yellowing of gasolines in storage. It was known also that mercaptans in the presence of elementary sulfur may be corrosive, and it was felt by many that the doctor test gave an indication of the total sulfur present in a gasoline. Therefore, it appears that the original sponsors of the doctor test intended that the test would provide gasolines having a sweet odor, better color stability, and less possibility of being corrosive.

During the past 20 years many changes have taken place within the petroleum industry. New treating processes and different conceptions of desirable gasoline characteristics now exist. From the consumer's point of view, performance characteristics—such as ease of starting, warmup, and knock characteristics—have assumed greater importance than color, odor, and a negative doctor test. From the refiner's point of view, the effects of various methods of treating upon overall gasoline-finishing costs and the antiknock characteristics of gasolines now must be evaluated more closely.

In general it now is recognized that gasoline specifications must be a compromise between two points of view—those of the consumer and of the manufac-

turer. Any specification which imposes an undue burden on one, without important advantages to the other, should not be standardized nor generally accepted. It is proposed in the following discussion to show that the doctor-test specification imposes a costly burden on the manufacturer, without corresponding advantages to the consumer.

Significance to Consumer

As previously mentioned, the three properties commonly associated with the doctor test are color, odor, and corrosion. As most gasolines at the present time are dyed for purposes of identification, their quality consequently is accepted on the basis of tests other than color. Many of the cracked hydrocarbons which now generally are considered highly desirable components of gasoline may form colored compounds on aging.

The emphasis upon gasolines having a "sweet" odor has been decreasing for many years, and it now is recognized generally that odor bears no relationship to gasoline quality. Except under unusual circumstances, the present-day car owner never smells the gasoline he uses, because of improvements in gasoline-tank construction and arrangement. Furthermore, the odor of so-called sweet gasoline is, in many cases, quite as objectionable as that of some gasolines containing small percentages of mercaptans. This situation may exist because the odor of gasoline depends to some extent upon other factors, such as type of crude from which the gasoline is derived and the method of processing.

As there is no general standard chemical or physical test for gasoline odor, a number of experiments were conducted for the purpose of obtaining some qualitative data on which an opinion as to allowable gasoline odors might be based, when using gasolines processed by different methods. Accordingly, a series of tests was made on several types of base gasoline-blending stocks containing known amounts of various pure mercaptans. Inspections of the various base gasolines are given in Table 1. Odors were measured according to two procedures. The first method was simply to sniff or smell the contents of a 4-ounce bottle of a gasoline or mercaptan blend to note its so-called apparent odor. The second method, which was used to study the residual odors, involved quickly pipetting 1 ml of each sample under test upon 1¼ x 1¼-inch sections of blotting paper. After 1 minute the blotter sections were compared for residual odor.

The odor tests shown in Tables 2, 3, and 4 were conducted using from 15 to 35 observers. In each of the tests a sufficient number of opinions was obtained for conclusive results. In Table 2 are the results of comparison tests for apparent odor, using the three base gasolines alone, which contained various percentages of mercaptans.

Table 3 gives results of apparent-odor comparisons, using some of the base-gasoline-mercaptan blends and 3 commercial gasolines having the worst odors of a group of 10 regular-grade gasolines marketed by different oil companies. Reference to this table shows that the apparent odors of some blends containing 0.005 percent by weight of mercaptan sulfur were better than those of some gasolines being marketed.

In Table 4 results of residual-odor tests, using both the prepared mercaptan blends and the three regular-grade gasolines referred to above, are shown. These tests showed somewhat different results from the apparent-odor tests, in that blends containing *n*butyl mercaptan gave worse residual odors than those containing methyl and *n*heptyl mercaptan in equivalent concentrations. In the apparent-odor tests, methyl mercaptan showed up worse than *n*butyl or *n*heptyl mercaptans. However, mercaptan blends containing up to 0.01 percent mercaptan sulfur were found to have residual odors as sweet as some gasolines marketed today.

Although the results of the odor tests shown in Tables 2, 3, and 4 give a measure of the relative odors of different mercaptan blends in comparison with each other and commercial gasolines, they do not give an absolute indication of what constitutes an acceptable odor. Obviously, it is necessary to have a larger number of observers for this purpose, inasmuch as personal taste as well as acuteness of sense of smell enters into the decision. A simple series of tests was arranged, in which 92 observers participated. Each observer was asked whether he considered the odors of each of three blends acceptable. The blends consisted of the straight-run gasoline base A, previously described, containing 0.003, 0.005, and 0.007 percent by weight of sulfur as *n*butyl mercaptan. In addition, each person was asked his opinion as to whether he felt that the odor of a gasoline necessarily was related to its quality, and if he ordinarily noticed the odor of gasoline put into his own or others' cars at filling stations. The answers obtained to these questions are given in Table 5.

The results of the odor-comparison tests made confirm the idea that the sensitivity of the doctor test for mercaptans is much greater than is necessary from the standpoint of acceptable gasoline odor.

Finally, the question of corrosion must be considered. The consumer, of course, is not interested directly in the effect of the mercaptan content of a gasoline upon its corrosiveness, so long as the gasoline itself is not corrosive. A satisfactory test for corrosion now is embodied in the *ASTM Standard Method of Test for Detection of Free Sulphur and Corrosive Compounds in Gasoline (D130-30)*.[5] This test is sufficiently severe to afford the degree of protection required for the metal parts in the fuel and induction systems of internal-combustion engines, and does

TABLE 1
Inspections of Base Gasolines

SAMPLE	A Straight-run Gasoline	B Thermally-Cracked Gasoline	C Catalytically-Cracked Gasoline
Gravity, deg. A.P.I.	62.1	59.0	56.2
ASTM Distillation, in °F.:			
Initial boiling point	106	100	90
10-percent point	145	148	137
20-percent point	175	187	172
30-percent point	205	218	204
40-percent point	232	242	230
50-percent point	254	262	251
60-percent point	276	279	277
70-percent point	298	296	305
80-percent point	322	324	329
90-percent point	352	355	355
End point	400	400	378
Recovery, percent	98.0	97.5	97.0
Residue, percent	1.0	1.0	1.0
Loss, percent	1.0	1.5	2.0
Reid vapor pressure, psi	9.3	9.4	9.0
Octane No., L-3 method	57.8	68.2	79.5
Doctor test	Sweet	Sweet	Sweet
Total sulfur, percent by weight	0.005	0.010	0.030
Composition, in percent:			
Olefins	3	29	14
Aromatics	16	27	40
Naphthenes	12	12	9
Paraffins	69	32	37

not impose an unnecessary burden of expense on the refiner by requiring special refinery processes.

As the corrosiveness of mercaptans is enhanced by the presence of free sulfur,[6] experiments were made to determine the influence of various concentrations of mercaptan sulfur and elementary sulfur—when present together in gasoline—upon the ASTM corrosion test. The base gasoline-blending stocks used in these experiments were freed of elementary sulfur by contacting with metallic mercury, and were made up to the desired concentrations by blending with carefully prepared solutions of elementary sulfur in the base gasolines. Pure *n*butyl mercaptan was used to provide the mercaptan sulfur in each blend. Each of the blends used in this work was sour to the doctor test. The data obtained in this investigation are shown in Table 6; and from this it appears that gasolines containing up to 0.005 percent by weight of mercaptan sulfur will pass the corrosion test, as long as the free sulfur content is less than 0.001 percent by weight. With a free-sulfur content of 0.002 percent by weight, a positive corrosion test probably will be obtained when the mercaptan-sulfur content exceeds 0.001 percent by weight. It is apparent, therefore, that the doctor test is no indication of the corrosiveness of a gasoline, and that this property is determined satisfactorily by a more direct method.

Although mercaptans and free sulfur are sensitive to the ASTM corrosion test when these are present together in a gasoline, much of the unsweetened stabilized gasoline prepared in present-day refinery equipment is not corrosive, due to insufficient free sulfur being present.

Considerations of the significance of the doctor test have been discussed entirely from the standpoint of color, odor, and corrosion. It is, of course, well-known that the doctor test has no significance with regard to the various performance characteristics of gasoline previously mentioned.

From the consumer's standpoint, it seems there is no reason why substantially higher mercaptan contents than are allowed by the doctor test could not be tolerated in gasoline.

Significance to Manufacturer

The final step in finishing raw gasoline from either crude or cracking stills is usually some chemical treating process intended primarily to remove or transform the mercaptans present. Today, in general, there are two types of processes available for gasoline finishing. In one the mercaptans are converted into oil-soluble disulfides by oxidation—as, for example, in the doctor process. In this type of process the sulfur content is not reduced; and, in fact, may be increased if care is not exercised in the amount of sulfur added to get a "break." Sulfur, disulfides, and mercaptans have an adverse effect on the lead susceptibility of gasoline;[7, 8, 9] and efforts have been directed in recent years to a second type of process, which removes mercaptans rather than converts them to disulfides. Countercurrent caustic washing is one process representative of this second type, and is effective in removing mercaptans—especially those having lower boiling points.[10] Yabroff and others[11] recently have reported that the addition of "solutizers"—such as potassium *iso*butyrate—materially increases the solubility of mercaptans in caustic alkali solutions, thus making the caustic scrubbing process adaptable to a greater range of stocks.

Experimental evidence presented by Henderson[8]

TABLE 2

Apparent-Odor Tests—Base Gasolines and Mercaptan Blends

COMPARISONS		
Best	**Medium**	**Worst**
A	C	B
A	C+0.005 percent h	B
C	A+0.005 percent h	B
A	A+0.002 percent b	B+0.002 percent m
B	B+0.002 percent h	B+0.002 percent b
A+0.005 percent m	C+0.005 percent m	B+0.005 percent m
A+0.005 percent b	C+0.005 percent b	B+0.005 percent b
A+0.005 percent h	C+0.005 percent h	B+0.005 percent h
A+0.005 percent h	A+0.005 percent b	A+0.005 percent m
A+0.005 percent b		A+0.010 percent h
B+0.005 percent h	B+0.005 percent b	B+0.005 percent m
B+0.010 percent h	B+0.005 percent b	B+0.005 percent m
C+0.005 percent h	C+0.005 percent b	C+0.005 percent m
C+0.010 percent h	C+0.005 percent b	C+0.005 percent m

Note: Gasoline blends were compared three at a time. All percentages given are percent by weight of mercaptan sulfur.
m=methyl mercaptan
b=*n*butyl mercaptan
h=*n*heptyl mercaptan

TABLE 3

Apparent-Odor Tests—Blends of Base Gasoline and Mercaptans, and Commercial Gasolines

COMPARISONS		
Best Gasoline D	**Medium Gasoline E**	**Worst Gasoline F**
A+0.005 percent b	Gasoline D	A+0.010 percent h
Gasoline D	B+0.010 percent h	B+0.005 percent m
C+0.010 percent h	Gasoline E	C+0.010 percent b
C+0.010 percent h	Gasoline E	C+0.010 percent m
B+0.010 percent h	B+0.005 percent b	Gasoline F
B+0.010 percent h	B+0.005 percent m	Gasoline F

Note: Gasoline blends were compared three at a time. All percentages given are percent by weight of mercaptan sulfur.
m=methyl mercaptan
b=*n*butyl mercaptan
h=*n*heptyl mercaptan

TABLE 4

Residual-Odor Tests—Blends of Base Gasoline and Mercaptans, and Commercial Gasolines

COMPARISONS		
Best	**Medium**	**Worst**
B+0.010 percent b	C+0.010 percent b	A+0.010 percent b
A+0.010 percent h	A+0.010 percent m	A+0.010 percent b
C+0.010 percent h	C+0.010 percent m	C+0.010 percent b
C+0.010 percent h	C+0.005 percent m	C+0.005 percent b
C+0.002 percent h	C+0.002 percent m	C+0.002 percent b
Gasoline D	Gasoline F	Gasoline E
C+0.010 percent h	Gasoline D	C+0.005 percent m
C+0.010 percent h	C+0.005 percent b	Gasoline F
C+0.010 percent m	Gasoline E	C+0.010 percent b

Note: Gasoline blends were compared three at a time. All percentages given are percent by weight of mercaptan sulfur.
m=methyl mercaptan
b=*n*butyl mercaptan
h=*n*heptyl mercaptan

TABLE 5

Opinions on Gasoline Odors

QUESTIONS	ANSWERS (Percent) Yes	No	Doubtful
1. Do you think the odor of a gasoline necessarily is related to its quality?	21.8	72.8	5.4
2. Do you ordinarily notice the odor of gasoline being put into your own or others' cars at filling stations?	19.6	78.2	2.2
3. Do you consider any of these gasolines to have an objectionable odor for a motor fuel?:			
A+0.003 percent by weight mercaptan sulfur	0.0	100.0	0.0
A+0.005 percent by weight mercaptan sulfur	14.1	85.9	0.0
A+0.007 percent by weight mercaptan sulfur	26.1	72.8	1.1

TABLE 6
Effect of Elementary and Mercaptan Sulfur in Gasolines upon ASTM Corrosion Test

BLENDS (Percent by Weight)		Results of ASTM Corrosion Tests		
Mercaptan Sulfur	Elementary Sulfur	Gasoline A	Gasoline B	Gasoline C
0.001	0.001	OK	OK	OK
0.001	0.002	Slightly corrosive	OK	Slightly corrosive
0.001	0.003	Corrosive	Corrosive	Corrosive
0.002	0.001	OK	OK	OK
0.002	0.002	Corrosive	Corrosive	Corrosive
0.002	0.003	Corrosive	Corrosive	Corrosive
0.005	0.001	OK	OK	OK
0.005	0.002	Corrosive	Corrosive	Corrosive
0.005	0.003	Corrosive	Corrosive	Corrosive

and Yabroff[9] indicates that the same gasolines, although carefully doctor-treated, require more tetraethyl lead to produce a given octane number when given an effective countercurrent caustic scrubbing. With use of either straight caustic or "solutizer" solutions, the lower-boiling mercaptans are removed more completely by caustic scrubbing; and as these compounds have the most objectionable odor for a given concentration in the same gasoline, the odor of a gasoline usually is reduced to a greater extent than the mercaptan removed would indicate.

The extent of mercaptan removal considered necessary by the refiner in processes of the latter type would depend entirely on the resultant lead savings effected, and would be different for varying stocks and manufacturing processes. The actual mercaptan concentration, for refinery-control purposes, conveniently may be measured quantitatively by any one of several convenient methods.[12, 13]

Practical Considerations

The elimination of the doctor-sweet gasoline specification, it is believed, can be accomplished in a practical manner.

The average gasoline consumer of today is much more conscious of factors governing gasoline performance than of the more superficial specifications which were considered significant in the past. He recognizes the importance of such items as mileage, freedom from knocking, satisfactory starting, and warmup. Just as the introduction of colored gasolines resulted in the abandonment of rigid color specifications, so the relatively small number of cases in which the consumer is in a position to be affected by gasoline odor militates against this item being of major importance in gasoline quality.

The limited acceptance of the doctor specification also should aid in its elimination. In fact, at the present time it does not appear in U. S. government specifications, and is required by the legal specifications of only one state.[14] The test has not been standardized by the American Society for Testing Materials. Most refiners purposely would market a gasoline that is not objectionable to the consumer, even if the doctor test were dropped; because economic considerations will limit the mercaptan concentration. Similarly, the refiner would be able in many cases to effect considerable economies in treating costs, by marketing a gasoline of slightly higher mercaptan content than would be allowed by the doctor specification. From the foregoing it is evident that elimination of the doctor test in no way would impair gasoline quality from the consumer's point of view, and would result in material savings to the petroleum industry.

Bibliography

[1] "Method 520.3," *U. S. Bur. Mines Tech. Paper 323 B*, 96 (1927).

[2] L. M. Henderson, M. S. Agruss, and George W. Ayers, Jr., "Effect of Sulful and Sulfur Compounds in Naphtha upon Certain Corrosion Tests," *Ind. Eng. Chem., Anal. Ed.* **12**, 1 (1940).

[3] "Report of U. S. Committee on Standardization of Petroleum Specifications," *Oil Division, U. S. Fuel Administration Bull. No. 1* Oct. (1918).

[4] G. W. Gray, "Gasoline Standardization in States," *Oil Gas J.* **17 [41]** 64 (1919).

[5] "Standard Method of Test for Detection of Free Sulfur and Corrosive Compounds in Gasoline," ASTM Designation D 130-30, *Book of ASTM Standards*, Part III, 206 (1939).

[6] Kalichevsky and Stagner, "Chemical Refining of Petroleum," *Am. Chem. Soc. Monograph No. 63*, 133 (1933).

[7] W. A. Schulze and A. E. Buell, "Sulfur Compounds Present in Motor Fuels Affect Lead Responsiveness," *Oil Gas J.* **34 [21]** 22-4 (1935).

[8] L. M. Henderson, W. B. Ross, and C. M. Ridgway, "Tetraethyl-Lead Susceptibilities of Gasoline," *Ind. Eng. Chem.* **31**, 27-30 (1939).

[9] D. L. Yabroff and A. C. Nixon, "The Improvement in Octane Number and Lead Susceptibility Resulting from Solutizer Sweetening," *Refiner* **19 [3]** 73 (1940).

[10] J. Happel and D. W. Robertson, "Removal of Mercaptans from Naphtha by Caustic," *Ind. Eng. Chem.* **27**, 941-3 (1935).

[11] D. L. Yabroff and L. E. Border, "The Solutizer Process for the Extraction of Mercaptans," *Proc. API* **20M [III]** 95-103 (1939).

[12] G. R. Bond, Jr., "Rapid Quantitative Determination of Mercaptans," *Ind. Eng. Chem., Anal. Ed.* **5**, 257 (1933).

[13] Charles K. Francis (editor), "Questions on Technology," *Oil Gas J.* **37 [41]** 110 (1939).

[14] *Digest of State Inspection Laws Relating to Petroleum Products*, Western Petroleum Refiners Assn., Tulsa, Okla., Nov. (1939).

Knocking Octanes

By C. H. VAN HARTESVELDT and H. W. FIELD
The Atlantic Refining Company, Philadelphia

OCTANE numbers of gasolines have received much attention in recent years in the public press, with the result that "high test" and "high octane" have become synonymous expressions; and the role of high-octane gasoline as a "cure-all" for the ills of motor-car performance has been accepted more widely than the facts warrant.

In this paper a comparison is presented of the value of improved automobile performance as observed by the "average driver," with the incremental costs of producing gasolines of successively higher octane numbers.

The automobile-performance observations have been made in car models now being operated by the public, rather than in engines specifically designed for extremely high-octane gasolines.

Further, it is notable, in view of many recent controversies, that "road octanes" are used throughout the discussion, even though it is admitted that the road-octane method leaves something to be desired in the way of reproducibility from car to car.

The improvement in the performance of present-day motor cars, as a result of wide-range increases in gasoline octane numbers, is shown to be minor relative to the increase in refinery cost of effecting these octane increases as reflected in potential reduction of the profit returns on investments in the petroleum industry.

A note of caution is struck, lest the refiners let competitive enthusiasm undermine the financial stability of the industry instead of proceeding on a sane and logical course of developments for the future.

This paper was presented to Division of Refining, before the Tenth Mid-Year Meeting of the American Petroleum Institute, at the Texas Hotel, Fort Worth, Texas, May 30, 1940.

OCTANE numbers are blooming this spring, and refiners needlessly may have plowed under prospective and justly earned profits to foster the floral display. Although the public rightfully expects, and will receive, steadily improved products from the petroleum industry, effort should be made at each step to equate the benefits to the consumer with the costs of the manufacturer.

In years past the industry has done a laudable job of passing along to the consumer the results of research and development, which have improved the quality of products and reduced the cost. However, during these same years, the exceedingly rapid developments of the automobile, going hand in hand with the improvement in petroleum products, resulted in changes—which were not only noticeable, but strikingly evident, to the general public.

Today both the automotive and the petroleum industries are working in zones where further improvements will require extraordinary efforts, unless radically different approaches to the problems are discovered. Certainly such innovations will be discovered, and both automotive and petroleum products will advance; but as increased anti-knock quality of gasoline does not come out of thin air, and as the petroleum industry now is operating in the narrowest margin between product cost and realization in its history, care should be taken that any costly increase in product quality is appreciated sufficiently by the consumer to warrant the expenditure necessary to produce it.

It is the purpose of this paper to present a comparison between the magnitude of improved automobile performance, as seen by the driver, with the incremental costs of producing gasolines of successively higher octane numbers. This study was made on car models now being operated by the public, and not on engines specifically designed for higher-octane gasolines. Further, the methods considered in the comparison of costs for improving octane numbers are those now available to the average refiner. The development of automotive engines for higher-octane fuels, and the development of special refinery processes for producing these fuels, are future problems that should be solved only by cooperative synchronization between the two industries concerned. This cooperation cannot be urged too strongly, inasmuch as the successful functioning of both industries vitally is concerned.

Improvements in performance, which can be gained by using higher-octane gasolines in present-day vehicles, were determined by gathering together available pertinent data and carrying out a sufficient number of additional tests to reveal the order of magnitude of performance changes of representative cars with variation in the octane number of the gasoline.

Octane-Number Determination

The octane numbers spoken of throughout this paper are "road" octane numbers. When car performance is dealt with, there is no substitute for octane-number determinations made in cars under driving conditions. Had any given laboratory method been used to evaluate the test fuels, their anti-knock quality on the road would not have been known, nor would the size of the steps from one fuel to the next have been apparent. However, even road octane numbers leave much to be desired. Ratings from one make of car to another are apt to differ, making an average of ratings in several makes necessary. Road ratings can vary also from car to car of the same make, but this variation is usually small, or can be corrected for the most part by mechanical adjustments.

The road octane numbers used in this paper are an average of the three ratings obtained on a 1938 or 1939

Ford, Plymouth, and Chevrolet—all in factory adjustment, and having run from 4000 to 10,000 miles. The octane numbers of the gasolines used to study the performance of the three 1938 cars in factory adjustment were obtained in those cars. Later, when 1939 cars were available and properly broken in, it was found that ratings in these cars were equivalent, make for make, to the 1938 ratings; and from then on the 1939 test cars were used for determining road octane numbers.

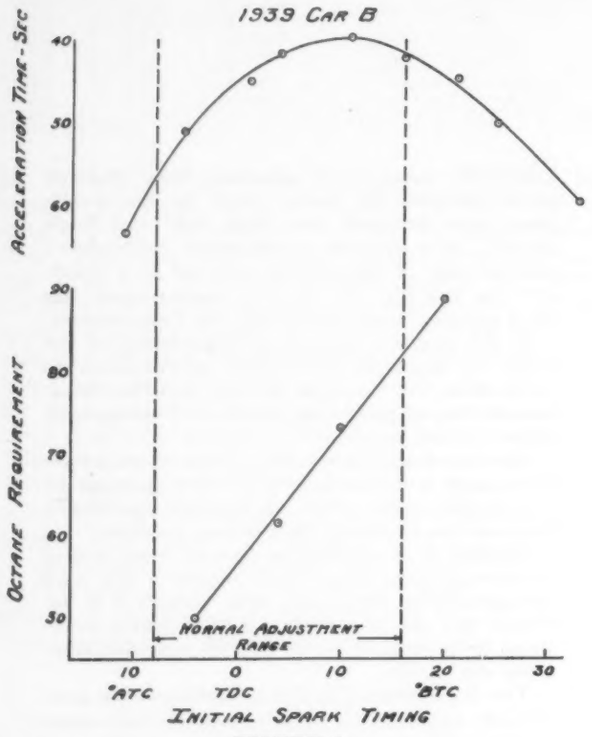


FIGURE 1
Typical Acceleration Times and Octane Requirements Vs. Initial Spark Timing

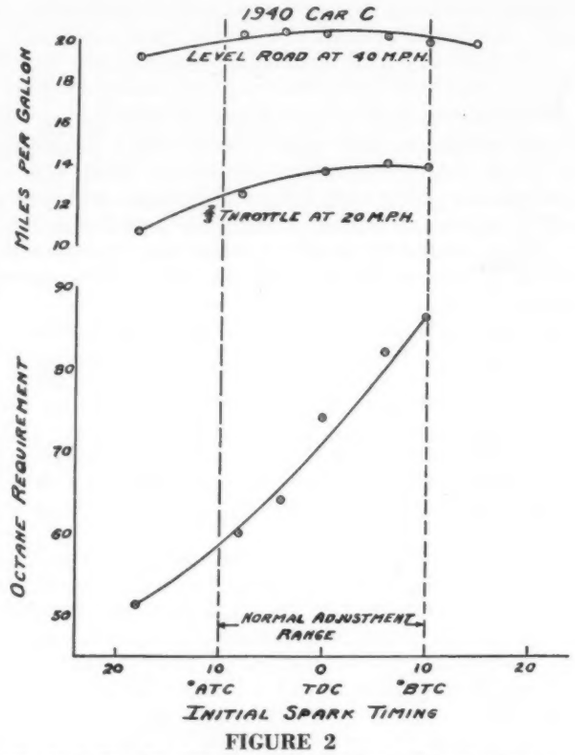


FIGURE 2
Typical Gasoline Mileage and Octane Requirements Vs. Initial Spark Timing

Advancing the Spark

One way by which an effort can be made to have the car owner appreciate a gain in car performance, when he is sold higher-octane gasoline, is to advance the basic spark setting. This presupposes that the car is in good mechanical adjustment, a supposition frequently contrary to fact. This is an important point, because many car ailments affect performance and octane requirement to such a large degree that the small improvement made possible by advancing the spark would not be noticeable.

To determine what might be accomplished in this way, one each of the three popular low-priced cars for 1938, 1939, and 1940 were studied. These cars had run from 1000 to 10,000 miles, and were in good mechanical condition. The distributor spark-advance characteristics were checked carefully to insure that each was in factory adjustment. The power available at different spark settings was determined from acceleration times taken with the car going up hill at full throttle on a non-knocking gasoline. It is believed that this is more a measure of what the car owner would find in his reaction to power improvements than constant-speed rear-wheel power measurements made on a chassis dynamometer. Between 30 and 40 seconds were required to ascend the test hill, the steepest portion of which being about a 7-percent grade. Following these runs, octane requirements were determined on the same hill over the range of spark settings previously investigated. Figure 1 presents the results of these investigations for one of the cars, and is typical of most. It will be noted that the experimental work was carried beyond the limits within which the spark normally can be advanced or retarded. This was done better to establish the shapes of the curves.

From these curves it was quite evident that, unless attempted improvements of car performance by adjustments to the spark timing are done intelligently, the purpose of the changes can be defeated, and the octane requirement for the car markedly increased to no avail.

Gasoline mileage was determined at 40 miles per hour on a chassis dynamometer with load equivalent to level road operation, and also load equivalent to upgrade, which would hold the cars at 20 miles per hour with 2/3 throttle opening. The upgrade conditions were simulated to permit measuring the change in gasoline mileage with spark advance under conditions which would give results comparable to those which would be expected during acceleration. Figure 2 presents a typical example of these results. Here again it can be seen that an advance of the spark timing can be carried to an extreme, which results in increased octane requirement without other advantageous accomplishments.

Table 1 tabulates the effect of road octane number on power with the basic spark setting of the car advanced to trace knock. In this summary and in subsequent summaries 74 octane number was chosen as 100 percent, as this grade represented the road octane number which was found for most regular-grade gasolines on the Eastern Seaboard at the time this work was carried out. The average figures in this table demonstrate the rela-

TABLE 1
Effect of Road Octane Number on Power, with Basic Spark Setting Advanced to Trace Knock

CAR	ROAD OCTANE NUMBER					
	68	71	74	77	80	83
1938 A	98.7	99.4	100.0	100.3	100.1	....
1938 B	99.9	99.9	100.0	100.1	100.2	....
1938 C	100.0	100.3	100.0	99.5	99.0	....
1939 A	96.0	98.4	100.0	101.9	104.5	105.4
1939 B	99.4	100.0	100.0	99.4	98.1	95.8
1939 C	88.6	94.5	100.0	105.2	109.0	111.6
1940 A	90.7	95.5	100.0	104.1	107.8	111.5
1940 B	94.5	97.9	100.0	100.7	100.7	99.2
1940 C	90.9	96.2	100.0	103.5	105.2	106.5
Average	95.4	98.0	100.0	101.8*	103.1*	105.9*

* Those less than 100.0 percent given value for optimum setting.

tive insignificance of the power improvements possible as compared with the major changes in octane-number-level requirement to effect these improvements. It is interesting to note that for some cars an actual decrease in the power available is obtained at octane-number levels higher than 74. This points to the fallacy of the feeling in the minds of garage men and public that "the better the gasoline (the more the spark can be set up) the peppier the car will be." It is very probable that many people, with their cars adjusted to trace knock, on a premium fuel actually are getting "third-grade" performance.

In Table 2 the effect of road octane number on gasoline mileage, with basic spark setting advanced to trace knock, is tabulated for level-road load at 40 miles per hour, and 2/3 throttle at 20 miles per hour. From these data it is quite evident that spark advance does not affect gasoline mileage to any significant extent on level-road operation, and under conditions simulating acceleration the mileage figures show exceedingly small differences in view of the wide range in octane number covered in the test work. The averages shown in Tables 1 and 2 are not figures that can be regarded as representing a grand average for any group of motor cars, but it is felt very definitely that these figures do show the order of magnitude of what can be done for car performance by increasing the octane number of the gasoline, without major mechanical alterations. The 3 cars used for the work are typical of 60 percent of the cars of their age now on the road, if all of them were put in good mechanical condition.

Work done on 1939 cars by the Institute's Automotive Survey Committee, and reported under the title of "Octane-Number Requirements of 1939 Cars with Spark Set for Maximum Torque," agrees well with the above results. The survey tested twenty 1939 cars of 14 different makes, and found that, when the basic spark setting was adjusted to the factory specification, the average octane requirement was 69.7. When the basic spark setting was advanced to give maximum torque at the speed at which maximum torque occurs, the average octane requirement was 80.1, and the average increase in torque was 3.4 percent. This figure can be compared to the 5.1-percent increase in power shown in Table 1 when going from a 71 to an 80 octane-number fuel. The larger differences shown in Table 1 probably are due to the fact that these figures represent acceleration times.

Gasoline-mileage variation with spark advance and, consequently, with octane number, as determined by this API committee, shows about the same variation as given in Table 2.

Performance with No Adjustment

When high-octane-number gasoline is used in a car which does not knock on the lower-octane material, no improvement in performance results; and when a car that knocks is fueled with a high-octane gasoline, the knock is reduced, but no additional power nor gasoline mileage is gained unless the knock was extremely loud. Knock must be so loud for power loss that no motorist with normal hearing, driving such a car, would fail to take the car to a repair shop. These things have been known for some time, but they deserve more emphasis than they are getting in present-day advertising.

To determine what difference occurs when a gasoline of high octane number is used and no mechanical adjustments made, 36 cars were chosen at random from ordinary service and tested, just as they were found, for power and mileage on a 74-octane gasoline and a 77-octane material. Both gasolines had the same API gravity, and very close to the same boiling range. All of this work was done on a chassis dynamometer, and rear-wheel horsepower was obtained on each fuel at 20, 35, and 50 miles per hour—gasoline mileage being determined at 30 and at 50 miles per hour for level-road load. For about half the cars, acceleration time at full throttle from 10 to 50 miles per hour also was taken under conditions simulating level-road power output; and other runs of this kind were made on all the cars, during which runs the knock intensity was noted by ear for comparison with that heard on the other test fuel.

All of the data gathered are shown in Table 3. Cars A, B, and C are the three most popular low-priced makes, and the number of these tested along with the cars listed in the fourth group gives a good cross-section of the cars on the road.

The overall average of gasoline mileage showing an 0.1-percent advantage for the 74-octane material is well within the limit of error of the test; and, likewise, the 0.5-percent advantage in acceleration time shown for the 74-octane gasoline is within the limit of error.

Only in the group of A cars do the power tests show a real advantage for the 77-octane fuel. This is because this group developed high engine temperatures and severe detonation during the relatively long-time full-throttle tests for rear-wheel horsepower. These tests were equivalent to running a car up the steepest grade negotiable at the speeds for which power was determined. It can be seen that this power test does not give similar results to the acceleration-time tests,

TABLE 2
Effect of Road Octane Number on Gasoline Mileage, with Basic Spark Setting Advanced to Trace Knock

CAR	ROAD OCTANE NUMBER					
	68	71	74	77	80	83
A. Level-Road Load at 40 Miles per Hour						
1938 A	99.9	100.0	100.0	100.0	100.1	....
1938 B	99.7	99.8	100.0	100.2	100.5	....
1938 C	100.0	100.0	100.0	100.0	100.0	....
1939 A	100.0	100.0	100.0	100.0	100.0	99.9
1939 B	99.4	99.9	100.0	99.9	99.8	99.5
1939 C	100.0	100.0	100.0	100.0	100.0	100.0
1940 A	98.9	99.5	100.0	100.6	100.8	101.0
1940 B	100.0	100.0	100.0	99.2	98.6	97.6
1940 C	100.2	100.2	100.0	99.8	99.6	99.4
Average	99.8	99.9	100.0	100.0	99.9	99.6
B. Two-thirds Throttle at 20 Miles per Hour						
1940 A	95.2	97.9	100.0	102.6	104.2	105.1
1940 B	97.5	98.9	100.0	101.0	101.7	102.0
1940 C	96.9	98.7	100.0	101.2	101.6	101.6
Average	96.5	98.5	100.0	101.6	102.5	102.9

TABLE 3

Chassis-Dynamometer Results on Cars from Ordinary Service Chosen at Random

Car No.	Make	Year	Mileage	74-ROAD-OCTANE GASOLINE: Power Tests (Horsepower) 20 MPH	35 MPH	50 MPH	Miles per Gallon 30 MPH	50 MPH	Maximum Knock on Acceleration	Acceleration Time 10 to 50 MPH	77-ROAD-OCTANE GASOLINE: Power Tests (Horsepower) 20 MPH	35 MPH	50 MPH	Miles per Gallon 30 MPH	50 MPH	Maximum Knock on Acceleration	Acceleration Time 10 to 50 MPH	PERCENTAGE DIFFERENCE*: Power 20 MPH	35 MPH	50 MPH	Economy 30 MPH	50 MPH	Acceleration Time	Customer Reaction to Different Knock Intensity on Accelerator
1	A	1937	19,468	16.3	33.4	49.0	17.1	16.1	Heavy+	25.3	16.9	33.4	47.9	17.1	16.1	Heavy+	27.2	+ 3.7	0.0	— 2.2	0.0	0.0	— 7.5	None
2	A	1937	25,230	22.6	42.7	53.2	18.7	16.6	Trace	.....	24.2	40.8	51.2	18.2	16.3	None	.....	+ 7.1	— 4.4	— 3.8	— 2.7	— 1.8	.....	Doubtful
3	A	1937	27,759	24.6	43.5	53.9	18.1	16.3	Trace+	16.6	24.3	42.6	51.1	18.3	16.0	None	16.3	— 1.2	— 2.1	— 5.2	+ 1.1	— 1.8	+ 1.8	Noticeable
4	A	1937	31,782	24.3	30.4	42.6	17.4	16.9	Light+	.....	25.9	36.3	53.5	17.7	16.7	Trace—	.....	+ 6.6	+19.4	+25.6	+ 1.7	— 1.2	.....	Noticeable
5	A	1938	.....	25.0	45.3	55.4	20.2	17.9	None	12.7	27.5	47.2	57.7	20.1	17.7	None	13.0	+10.0	+ 9.0	+ 8.1	— 0.5	— 1.1	— 2.4	None
6	A	1938	15,559	25.3	42.1	53.5	19.1	16.1	Med.+	.....	25.9	46.0	53.2	19.1	16.1	Trace	.....	+ 2.4	+ 9.3	— 0.6	0.0	0.0	.....	Noticeable
7	A	1938	23,640	25.0	45.5	56.3	19.4	17.4	.....	13.2	25.3	46.3	57.4	19.3	17.2	Light—	12.8	+ 1.2	+ 1.8	+ 2.0	— 0.5	— 1.1	+ 3.0	.....
8	A	1938	32,273	25.9	47.0	59.5	19.7	17.3	Lt. Med.+	.....	26.4	47.2	59.2	19.7	17.5	Light+	.....	+ 1.9	+ 0.4	— 0.5	0.0	+ 1.2	.....	Doubtful
Average	A	.....	.....	.....	.....	.....	.....	.....	.....	16.9	.....	.....	.....	.....	.....	.....	17.3	+ 4.0	+ 4.8	+ 2.9	— 0.2	— 1.0	— 1.3	.....
9	B	1936	19,150	23.3	40.8	54.9	19.9	18.2	None	14.8	22.8	40.5	53.2	19.5	17.9	None	14.7	— 2.1	— 0.7	— 3.1	— 2.0	— 1.6	+ 0.7	None
10	B	1936	38,223	24.2	42.0	56.0	17.3	16.3	None	14.5	24.4	42.4	56.2	17.1	16.2	None	14.6	+ 0.8	+ 1.0	+ 0.4	— 1.2	— 0.6	— 0.7	None
11	B	1937	35,493	21.0	36.9	48.7	20.5	18.6	Trace	.....	21.2	37.6	52.1	20.2	18.8	None	.....	+ 1.0	+ 1.9	+ 7.0	— 1.5	+ 1.1	.....	Doubtful
12	B	1938	17,188	25.8	45.2	60.1	18.8	16.9	Trace	.....	25.3	43.1	57.7	18.6	16.9	None	.....	— 1.9	— 4.6	— 4.0	— 1.1	0.0	.....	Doubtful
13	B	1938	22,350	19.9	35.9	49.6	19.4	19.3	Light—	.....	19.5	34.9	47.6	18.8	19.0	Trace+	.....	— 2.0	— 2.8	— 4.0	— 3.1	— 1.6	.....	None
14	B	1939	4,549	21.8	38.2	53.2	20.2	17.9	None	14.7	21.8	37.6	54.6	19.9	18.1	Trace	15.5	0.0	— 1.6	+ 2.6	— 1.5	+ 1.1	— 5.4	Doubtful
15	B	1939	7,215	22.8	41.5	57.4	22.4	20.3	Trace+	.....	23.3	42.3	58.8	22.6	20.4	Trace—	.....	+ 2.2	+ 1.9	+ 2.4	+ 0.9	+ 0.5	.....	Doubtful
16	B	1939	11,500	21.6	39.5	51.5	20.9	18.5	Trace	15.1	21.6	39.2	52.9	20.8	18.6	None	14.8	0.0	— 0.8	+ 2.7	— 0.5	+ 0.5	+ 2.0	Doubtful
17	B	1939	18,059	20.9	35.8	50.0	20.6	18.1	Trace	17.6	21.0	36.4	50.3	20.6	17.7	Trace	18.2	+ 0.5	+ 1.7	+ 0.6	0.0	— 2.2	— 3.4	None
18	B	1940	835	22.6	41.0	57.1	19.4	18.4	None	13.3	22.5	41.0	57.4	19.6	18.6	None	13.6	— 0.4	0.0	+ 0.5	+ 1.0	+ 1.1	— 2.2	None
Average	B	....	.....	.....	.....	.....	.....	.....	.....	15.0	.....	.....	.....	.....	.....	.....	15.3	— 0.2	— 0.4	+ 0.5	— 1.0	— 0.2	— 1.5	.....
19	C	1936	22,491	21.6	37.4	49.7	19.4	17.3	Trace	.....	21.9	35.3	46.6	19.2	17.2	None	.....	+ 1.4	— 5.6	— 6.2	— 1.0	— 0.6	.....	Doubtful
20	C	1938	.....	18.9	36.5	49.0	20.8	17.8	Lt. Med.—	20.0	19.6	36.1	46.7	20.7	17.8	Trace+	20.6	+ 3.7	— 1.1	— 4.7	— 0.5	0.0	— 3.0	Noticeable
21	C	1938	.....	20.8	35.8	47.6	20.5	18.0	Lt. Med.—	.....	20.5	34.8	45.6	21.1	18.5	None	.....	— 1.4	— 2.8	— 4.2	+ 2.9	+ 2.8	.....	Noticeable
22	C	1939	2,404	23.8	39.8	53.1	22.0	18.5	Heavy+	14.1	23.9	39.1	52.0	22.0	18.8	Med. Hy.+	13.7	+ 0.4	— 1.8	— 2.1	0.0	+ 1.6	+ 2.8	Doubtful
23	C	1939	7,675	23.9	39.8	53.6	21.5	18.6	Trace	.....	23.7	39.4	51.9	21.4	18.8	Trace	.....	— 0.8	— 1.0	— 3.2	— 0.5	+ 1.1	.....	None
24	C	1939	14,833	22.9	38.4	49.5	20.0	17.7	Light	14.8	22.1	37.6	48.8	19.3	17.9	Trace	14.8	— 3.5	— 2.1	— 1.4	— 3.5	+ 1.1	0.0	Doubtful
25	C	1940	852	23.1	38.0	53.2	21.3	18.8	Light+	15.6	23.1	38.2	52.1	20.8	18.6	Light	15.5	0.0	+ 0.5	— 2.1	— 2.3	— 1.1	+ 0.6	None
26	C	1940	1,458	24.4	41.7	56.7	20.6	18.8	Light—	.....	25.5	41.5	54.4	20.1	19.4	Trace	.....	+ 4.5	— 0.5	— 4.1	— 2.4	+ 3.2	.....	Doubtful
Average	C	.....	.....	.....	.....	.....	.....	.....	.....	16.1	.....	.....	.....	.....	.....	.....	16.1	+ 0.76	— 1.8	— 3.5	— 1.0	+ 1.2	+ 0.1	.....
27	D	1936	25,861	24.5	42.1	54.6	18.3	17.6	Light—	.....	24.4	42.2	55.4	18.5	17.5	Trace	.....	— 0.4	+ 0.2	+ 1.5	+ 1.1	— 0.6	.....	Doubtful
28	D	1937	35,039	26.5	43.7	56.0	16.8	15.2	None	12.2	26.5	44.7	55.7	16.6	15.9	None	12.4	0.0	+ 2.3	— 0.5	— 1.2	+ 4.6	— 1.6	None
29	D	1938	21,722	25.3	43.0	55.3	.....	.....	Light+	12.9	25.8	43.0	55.0	.....	.....	None	12.7	+ 2.0	0.0	— 0.5	.....	.....	+ 1.5	Noticeable
30	D	1939	3,768	28.0	47.6	60.0	20.0	16.8	Trace	11.2	28.2	48.9	61.8	20.3	16.7	Trace —	11.2	+ 0.7	+ 2.7	+ 3.0	+ 1.5	— 0.6	0.0	None
31	E	1939	2,575	30.4	56.1	71.8	17.5	15.6	Light	.....	30.6	55.8	71.7	18.0	15.6	None	.....	+ 0.7	— 0.5	— 0.1	+ 2.9	0.0	.....	Noticeable
32	E	1939	5,696	30.5	56.5	73.1	17.9	16.2	Light—	.....	30.7	57.7	74.5	18.2	15.8	Trace	.....	+ 0.7	+ 2.1	+ 1.9	+ 1.7	— 2.5	.....	Doubtful
33	F	1937	33,317	27.2	46.8	60.5	19.2	16.9	Light	12.0	26.9	45.7	58.0	19.2	17.2	Trace	11.7	— 1.1	— 2.4	— 4.1	0.0	+ 1.8	+ 2.5	Doubtful
34	G	1939	14,404	23.9	42.9	57.1	20.5	17.6	Trace	.....	25.2	42.3	56.2	20.2	17.5	None	.....	+ 5.4	— 1.4	— 1.6	— 1.5	— 0.6	.....	Doubtful
35	H	1939	2,650	27.7	43.7	58.5	20.6	17.1	None	.....	27.6	45.3	60.5	20.5	17.2	None	.....	— 0.4	+ 3.7	+ 3.4	— 0.5	+ 0.6	.....	None
36	I	1937	17,200	27.7	48.7	64.2	16.3	14.8	None	11.8	27.7	48.6	63.1	16.3	14.8	None	11.8	0.0	— 0.2	— 1.7	0.0	0.0	0.0	None
Average	.....	.....	.....	.....	.....	.....	.....	.....	.....	12.0	.....	.....	.....	.....	.....	.....	12.0	+ 1.0	+ 0.7	+ 0.1	+ 0.6	+ 0.5	+ 0.8	.....
Overall Average	.....	.....	.....	.....	.....	.....	.....	.....	.....	14.9	.....	.....	.....	.....	.....	.....	15.0	+ 1.4	+ 0.8	0.0	— 0.4	+ 0.1	— 0.5	.....

* Plus sign favors 77-octane fuel. Minus sign favors 74-octane fuel.

the reason being that the time required in the latter case is short enough to prevent overheating.

The acceleration tests for knock showed that the 77-octane gasoline reduced the knock in those cars in which detonation occurred. The general method by which the knock intensity was recorded is the same as that used in making CFR road tests. The lightest knock audible is called "trace minus," and the next loudest knock distinguishable is called "trace." The complete scale determined in this manner is as follows:

1. Trace minus
2. Trace
3. Trace plus
4. Light minus
5. Light
6. Light plus
7. Light medium minus
8. Light medium
9. Light medium plus
10. Medium minus
11. Medium
12. Medium plus
13. Medium heavy minus
14. Medium heavy
15. Medium heavy plus
16. Heavy minus
17. Heavy
18. Heavy plus

Recognizing so many intensities of audible knock may appear to be quite a feat, but the high order of accuracy with which it can be done by trained personnel has been demonstrated. In this test work the important measure of knock to be made was the number of steps between the knock which occurred with the 74- and with the 77-octane-number gasolines, and not the absolute intensity. This comparison was made more significant by running the two fuels consecutively as many times as the operator desired to make sure of the result.

To estimate the effect of differences in knock intensities on customer reaction, it was decided that an average driver would not notice changes of one step, and that it was doubtful whether differences of as much as two steps would be heard. It was felt that all differences larger than two steps definitely would be noticed. On this basis a summary of the knock-intensity results shows that in 13 cars no difference would be found; in 14 cars the 77-octane fuel showed less knock, but it would be doubtful whether an average driver would notice it; and in only 7, or approximately 20 percent of the cases, would a customer notice a definite difference.

To sum up, the comparison of a 77-octane gasoline with a 74-octane fuel is:

1. No difference in gasoline mileage.
2. No difference in acceleration time.
3. An average of 1.8 percent improvement in "long-pull" power.
4. a. Approximately 40 percent of cars—no difference in knock.
   b. Approximately 40 percent of cars—difference in knock in favor of 77-octane fuel is doubtful.
   c. Approximately 20 percent of cars showed noticeable reduction in knock with the 77-octane gasoline.

Looking over these results, it is evident that many customers will not appreciate efforts to increase their driving satisfaction, if such efforts involve only increasing gasoline octane number. In the long run the petroleum industry will suffer, rather than benefit, by permitting false impressions of this nature to persist.

TABLE 4
Effect of Distributor Adjustment on Octane Requirement and Power

CAR	Before Distributor Adjustment		After Distributor Adjustment	
	Octane Requirement	Average Rear-Wheel Horsepower; 20, 35 and 50 Miles per Hour	Octane Requirement	Average Rear-Wheel Horsepower; 20, 35 and 50 Miles per Hour
1938 A'.....	83.3	27.6	78.5	28.4
1938 B'.....	59.8	24.4	56.4	25.8
1937 C'.....	80.6	23.2	78.6	26.3
1938 C'.....	83.1	26.2	71.4	28.8
1939 C'.....	76.4	36.9	74.4	37.6
Average...	76.6	27.6	71.9	29.4

Maintenance

A much sounder and more profitable note for the oil industry to strike would be "proper maintenance." Some mechanical troubles cannot be solved by gasoline quality. Car No. 1 is a good example of this. Examination after the test showed that the spark-advance mechanism of the distributor behaved in a very erratic manner. The results of this can be seen in a comparison of the power measurements on this car with other cars of the same make. A few dollars spent for a distributor adjustment or replacement would do far more toward this car owner's driving pleasure than the reduction in knock he might gain by using a premium fuel. Undoubtedly, many more of the cars tested could have had similar improvements made.

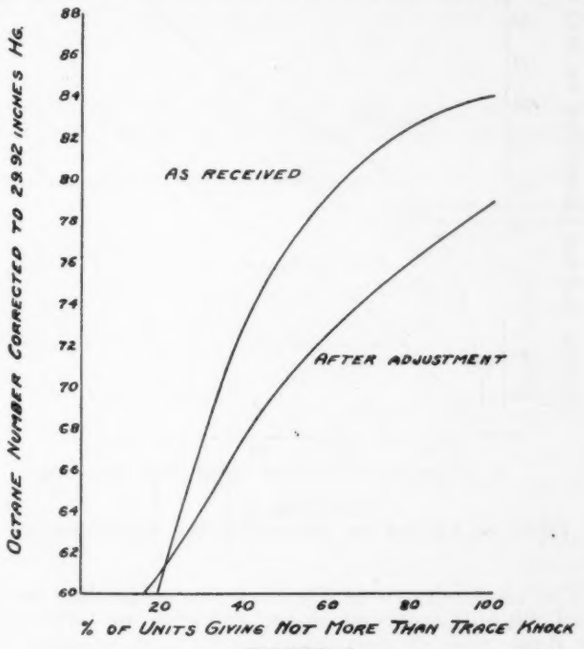


FIGURE 3
Octane-Number Requirement Before and After Adjustment

Proper adjustment of the distributor, with reduction in octane requirement and an increase in power, is probably a common occurrence; but the means for measuring power generally are not available when these adjustments are made. In work done by The Atlantic Refining Company in the 1939 CFR motor survey, 6 cars were chosen as having abnormal octane requirements. Full-throttle rear-wheel power measurements were made at 20, 35, and 50 miles per hour before and after the repairs were made to the distributor, with results shown in Table 4.

After adjustment, an average drop of 4.7 octane numbers occurred in the car requirements, with an increase of 6.5 percent in power.

In 1939 one of the several investigations made in the annual CFR motor survey was a study of the reduction in octane-number requirement of various cars, when the distributor was adjusted so that it functioned according to the manufacturer's intentions. Fourteen organizations, including major oil and automobile companies, aided in gathering data on the 23 models of 1939 cars, and Figure 3 shows the results

from the data gathered on octane requirement as the cars were received and after the distributor adjustment had been made. The curve is taken from the CFR motor-survey report, 1939, by D. B. Brooks, of the National Bureau of Standards. It can be seen that proper adjustment was worth close to 6 octane numbers on 60 percent of the cars examined.

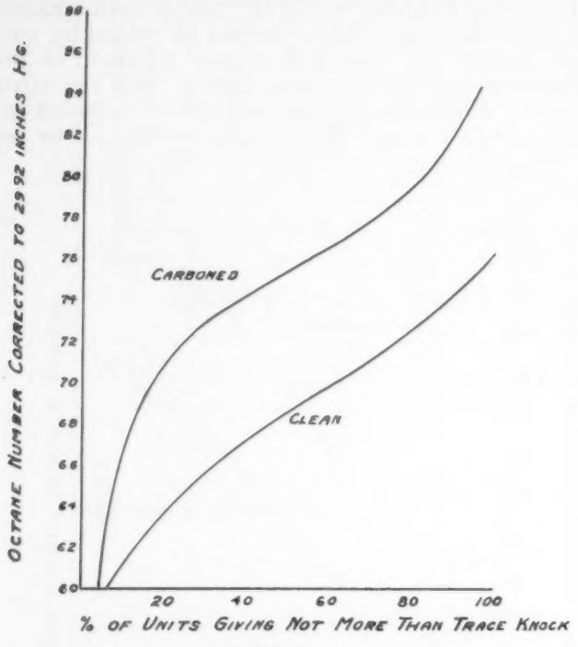


FIGURE 4
Effect of Carbon on Octane-Number Requirement

The curve shown in Figure 4 also was taken from the CFR motor-survey report, and it shows what can be done toward reducing octane requirement by carbon removal. For 80 percent of the cars the reduction was 7 numbers.

When men buy themselves a new gun, or fishing tackle, or a camera, they usually take great care in the proper handling and preservation of such mechanisms. With an automobile, it seems to be the fashion to do as little as possible along these lines. Automobile companies hesitate to stress the need of maintenance for fear of admitting that the car is not good enough to forego attention to working parts, and the advice of the garage man may be looked upon as sales promotion. The oil companies could promote educational programs stressing proper mechanical maintenance, which would benefit all groups concerned—and themselves in particular.

As a general summary of the foregoing investigations, it is impossible to reach any conclusion other than that present-day cars are not designed for extremely high-octane gasoline, and do not show appreciable improvements in performance or economy when run on a high-octane fuel. Further, the relatively few cars which do show improved performance characteristics when using the high-octane gasoline probably could give greater owner satisfaction if carbon were cleaned or mechanical adjustments made, and if the cars then were run on the lower-octane fuel.

Cost of High-Octane Gasoline

In view of the picture presented thus far—which certainly throws considerable doubt on the ability of the average automobile driver to recognize and appreciate driving his car on gasolines having octane numbers above 74—it is pertinent to inquire into the cost of furnishing this material. For convenience in making this inquiry, the term "barrel octane number" will be used, and the cost of a barrel octane number will be either the cost of raising a 42-gallon barrel of gasoline 1 octane number, or the incremental cost of producing a barrel of gasoline at an octane level one number higher than previously.

The cost per barrel octane number varies quite widely, depending upon the individual refinery situation; and, hence, an absolute figure for the entire industry cannot be stated. Further, this cost increases as the octane level increases; i.e., costs more to produce an 81-octane gasoline compared with an 80- than to produce a 71-octane gasoline compared with a 70-.

For the purpose of this discussion it will be assumed that the starting level is 74 octane—which level is perfectly satisfactory for the great majority of the cars on the road, provided they are kept in reasonably good mechanical condition. In addition, it will be assumed that for some reason, competitive or otherwise, octane levels will be advanced to 80. With these as a basis and as a result of the accumulation of a large amount of data on cracking costs, reforming costs, susceptibility of various motor fuels to octane increase by the use of tetraethyl lead, and consideration of yield decreases of gasoline from crude when producing higher octane levels, it has been concluded that a reasonable cost per barrel octane number in the range 74 to 80 would be 5 cents.

More than 500,000,000 barrels of gasoline are being produced per year in this country. The total cost of changing the octane number of all of this gasoline through the six-point range indicated reaches $150,000,000 per year. This figure is admittedly high, as the chance that the entire production of gasoline would be shifted through this complete range does not seem to be great. However, an examination of the past and present octane trends gives no comfort that such a change is impossible.

To the refining industry, this situation is fraught with grave possibilities. In 1939 the industry earned $400,000,000, which is not particularly good, as it represents only 5 percent of the net worth. The increased cost of the octane jump, therefore, represents almost 40 percent of the industry earnings.

There are about 30,000,000 motor vehicles in use in this country. If this increased cost were passed on to the consumer, the average would be $5 per year per vehicle, an insignificant percentage of the total cost of motor-vehicle operation.

It should be emphasized that the purpose of this paper is not one advocating a stand in the way of progress. As mentioned earlier, new automotive designs and new refinery processes certainly will result in the future, and these will give the automobile owner even more in the way of owner satisfaction per dollar than he is getting now. It is the hope that this presentation will bring to light more facts and some comparisons which may have been overlooked heretofore with regard to the present relationship between engine design and gasoline quality. The petroleum industry has in the past, and will in the future, produce gasolines to give satisfactory performance in any engine which results from improvements in automotive design. At the present time, however, the petroleum industry seems to be running a race with itself which does not offer promise of any tangible accomplishments, and which will cost a large sum of money which should be put to more productive uses.

Elimination of Hydrate Troubles*

By E. G. HAMMERSCHMIDT
Texoma Natural Gas Company

NEARLY all freezing troubles in natural gas pressure systems are caused partially or entirely by hydrocarbon hydrates, crystalline chemical compounds of methane, ethane, propane or isobutane in which water is present in simple molecular proportions. Natural gasoline and liquefied petroleum gas manufacturers are directly concerned with the hydrate problem wherever they are dealing with high-pressure gas at moderately low temperatures. Hydrate troubles in high-pressure gas systems may be permanently eliminated by removing the water condensate in the system, together with a sufficient amount of the water vapor in the high-pressure gas so that additional condensation cannot occur at minimum temperature and maximum operating pressures. In other words the dew point of the gas must be at least as low as the minimum temperature of the system when it is at maximum operating pressure. (Dew point is defined as the temperature of the gas at which liquid water begins to form.) A partial dehydration, or dehumidification, of the gas is therefore sufficient to meet the operating requirements of a great many high pressure systems. The operating cost of a dehumidification plant falls within the range of 0.02 to 0.12 cent per 1000 cubic feet, according to Shively.[9] Baker and Partridge[1] state that the expense of full-time operators at a dehumidification plant is by far the largest item of operating cost. They also indicate that in certain cases, these plants may be made fully automatic, in which case the services of full-time operators may be dispensed with. Clark[4] reports an operating cost of 0.116 cent per 1000 cubic feet for a combination refrigeration and brine absorption plant. This cost was based on one year of operation at a daily throughput of 45,000,000 cubic feet and during this period, half of the time of one man was sufficient to control operation, which is stated to be nearly automatic.

Liquid Absorbents

The magnitude of the dew point lowering that may be effected by any aqueous hygroscopic mixture is dependent both upon the contact temperature and the nature of the hygroscopic material. The residual water vapor content of the dehumidified gas is also affected by the total pressure on the system. The equilibrium dew point curves for a number of hygroscopic solutions are presented herewith in graphical form. For comparative purposes the following tabulation has been prepared from data that were taken from these curves. This tabulation represents the maximum dew point depression under equilibrium condition at the two indicated contact temperatures.

SOLUTIONS	Dew Point Depression at Contact Temperatures of 90 °F.	40 °F.
Lithium Chloride	67 °F.	40 Approx.
Dew-SA (Calcium Bromide-Calcium Chloride)	64	29
Zinc Chloride	55	40 Approx.
Diethyleneglycol (96 percent)	51	45
Calcium Chloride 40 percent—Glycerine 20 percent	41	23
Glycerine (85 percent)	33	30
Calcium Chloride (40 percent)	31	23

In order to illustrate the effect of pressure on the residual water vapor content, assume that equilibrium conditions have been established between the gas and a 40 percent solution of calcium chloride at 90° F. From the above tabulation, we see that a dew point depression of 31° F. may be obtained, i.e., the equilibrium dew point will be $90 - 31 = 59°$ F. If the total pressure on this system is 200 pounds per square inch the residual water vapor content of the treated gas will be 61.5 pounds per million cubic feet; at 500 pounds per square inch the water vapor content will be 26.3 pounds per million cubic feet and at 800 pounds per square inch it will be 17.3 pounds per million cubic feet. These examples clearly show that a dehumidification plant is much more effective in stripping a gas of its water vapor when it is placed on the discharge side of a compressor station rather than on the lower pressure intake side, temperature conditions being the same.

Of the various types of hygroscopic solutions that were mentioned above, calcium chloride brine and diethylene glycol solutions have been used most frequently on high-pressure-natural-gas systems. The chief advantage of calcium chloride as compared with diethylene glycol appears to be in the lower cost of the former material. The annual solution make up requirement at three calcium chloride dehumidification plants ranged from 0.1 to 0.2 pounds $CaCl_2$ per million cubic feet of treated gas. An aqueous solution of calcium chloride is a good electrolyte and care must be used in the selection of equipment in order to prevent electrolytic corrosion between dissimilar metals. The results of practical operation show that concentrated solutions of calcium chloride at atmospheric or lower temperatures are not corrosive in an atmosphere of natural gas unless the pH of the brine solution falls to 4.2 or less. The amount of dissolved iron in the system brine may be indica-

* Before the annual meeting of the Natural Gasoline Association of America, May 17, 1940, Tulsa, Oklahoma.

tive of the corrosiveness of the solution as shown by the following analyses:

	Dissolved Iron P.P.M. in 30% $CaCl_2$	pH
Plant No. 1	62	4.7
Plant No. 2	355	4.4
Plant No. 3	1111	4.2

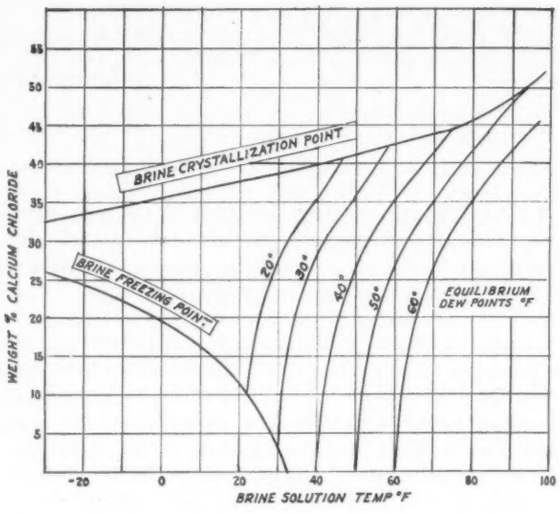
Some active corrosion has been observed in the contacting tower at plant No. 3 but no appreciable corrosion has been found at plants 1 and 2. Calcium chloride brine has been in continuous use at plant No. 1 since August 1933. The only point in the system where active corrosion has been observed is in the high temperature evaporating tank. Shively[9] reports that the average life of a cast iron evaporator is about 5 years. The life of a steel evaporator is probably about 2 years.

Accumulations of oil such as absorption oil that may collect in the system during normal operation of a dehumidification plant should be withdrawn separately from the hygroscopic solution in order to present the formation of permanent emulsions that will occur if the two solutions are drained simultaneously from a high-pressure system and vented to atmospheric pressure.

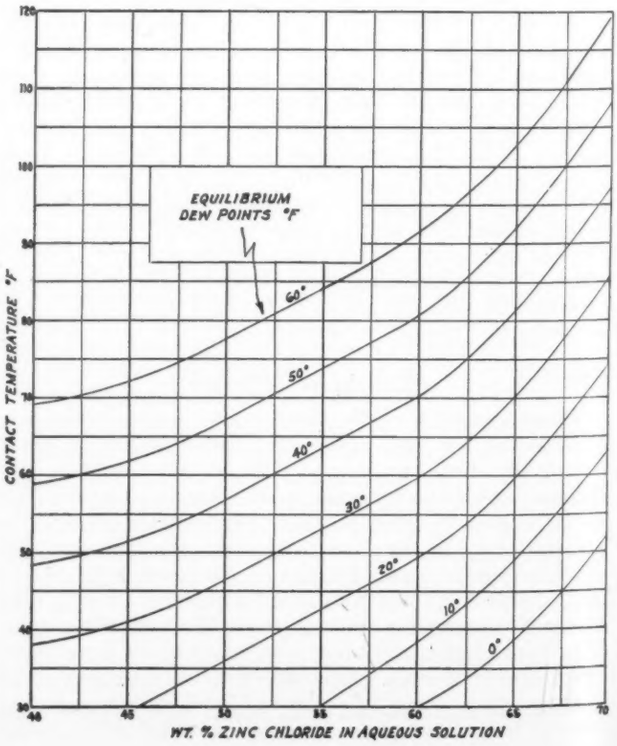
The magnitude of the dew point depression in a calcium chloride brine system at any fixed temperature is limited by the solubility of the calcium chloride at that temperature. It is necessary to operate with brine concentrations that are well below the crystallization point in order to prevent plugging of the solution lines. However, an inspection of the calcium chloride equilibrium dew point chart will show that sufficient dew point depression can be obtained from most commercial operations providing that the contact temperature is low enough. Low contact temperatures usually require the installation of refrigeration equipment which will materially increase the cost of a dehumidification plant. It may therefore be more economical to select a hygroscopic material that is capable of producing lower dew points than calcium chloride brine. A mixture containing 40 percent calcium chloride, 20 percent glycerine and 40 percent water has been used for this purpose in at least two commercial plants.

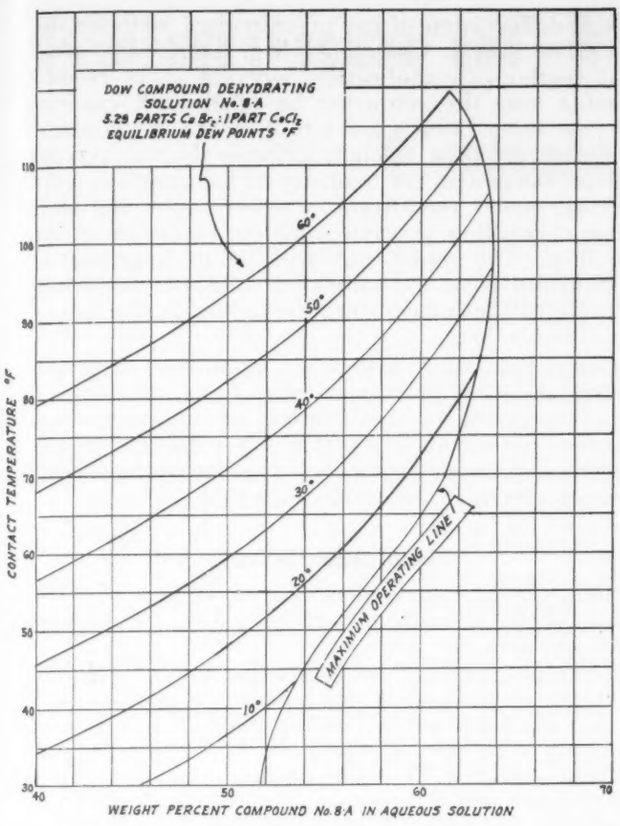
The equilibrium dew point of this mixture is approximately equivalent to a saturated solution of calcium chloride. The addition of glycerine to supersaturated calcium chloride solutions is said to interfere with the crystallization of the calcium chloride in such a manner that it is precipitated in a finely divided form so that the resulting mixture is readily maintained in suspension in the solution.[6] The solution makeup requirement at one of these plants is about .02 to .06 gallon per million cubic feet where the plant throughput is 100 to 130 million cubic feet per day and the contactor pressure is about 200 pounds per square inch. Baker and Partridge[1] report that operating troubles of a glycerine chloride plant have been negligible except when small amounts of hydrogen sulfide were present in the gas. The hydrogen sulfide was believed to have formed iron sulfide which acted on mineral seal oil that was present in small amounts and resulted in foaming of the solution.

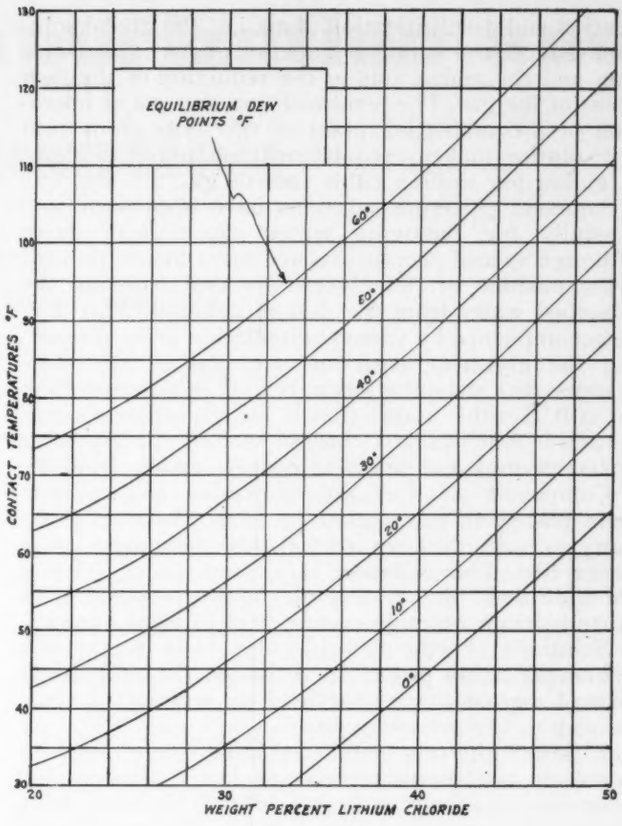
Diethylene glycol was introduced as a commercial dehumidifying agent in 1936 and at least 17 plants of this type are now in operation. Diethylene glycol is an organic liquid that solidifies at 14° F. A 95 percent aqueous solution solidifies at about —40° F. The aqueous solution can therefore be used in practically all commercial operations without the danger of solidification that is present in the case of concentrated calcium chloride solutions. The dew point



lowering at any given temperature is greater than could be attained with any practical concentration of calcium chloride brine or with the 40 percent calcium chloride-20 percent glycerine mixture. Operating difficulties of this type of plant are also reported to be nil. Baker and Partridge[1] reported that diethylene glycol absorbs some condensable hydrocarbons, e.g., 25 gallons per day of heavy gasoline was condensed with the water from the still outlet vapors, in a plant that was designed to treat 50

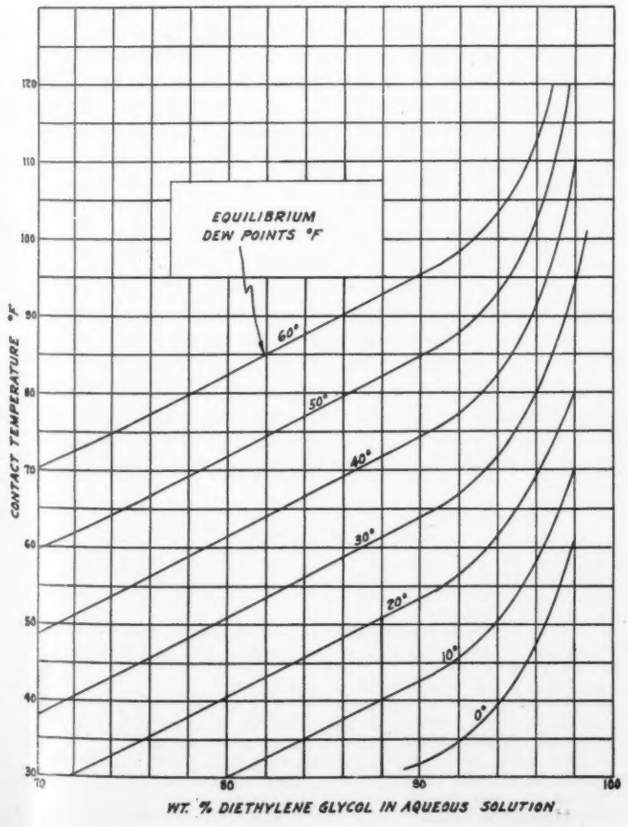


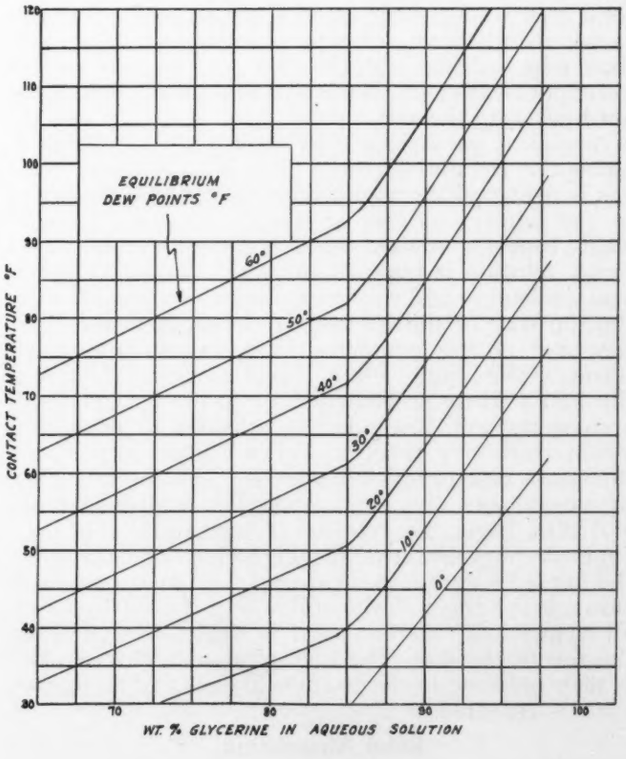




million standard cubic feet per day at 300 to 425 pounds per square inch, operating pressure. Laboratory tests showed no absorption of gasoline at 80° F. and 750 pounds per square inch when contacted with a dry gas which contained 0.300 gallons per 1000 cubic feet. The solubility of the gas at the same temperature and pressure was found to be .345 cubic feet per pound of diethyleneglycol.[12]

Diethylene glycol and the ethanolamines appear to be mutually beneficial in a combination dehumidi-





fication and desulfurization plant, i.e., the glycol solution reduces the foaming tendency of the amine solution and the amine aids in the reduction of the dew point of the gas. The results of two seasons of operation of a combination plant of this type show that the solution makeup requirement amounted to about .1 gallon per million cubic feet of gas.

Aqueous glycerine solutions have been used successfully for removing water vapor from gases although special precautions are necessary to prevent decomposition of the glycerine when removing the absorbed water from the diluted solution. This may be accomplished by vacuum distillation or by contacting the glycerine with an inert gas in the same manner that stripping steam is used in an absorption oil still. Smith[10] states that if the glycerine concentration is much greater than 85 percent, the glycerine is too viscous and tends to cause foaming troubles.

Compound solution No. 8A which has recently been placed on the market by Dow Chemical Company is said to have remarkable dehumidification properties. This solution is a mixture of calcium bromide and calcium chloride in the proportion 5.3 parts calcium bromide to one part calcium chloride.

Solutions of zinc chloride also have remarkable dehumidification properties although the probability of acid corrosion has prevented its practical application up to the present time.

Lithium chloride solutions have been used for some air conditioning problems but it has not yet been used in a large scale gas dehumidification plant. Bichowsky[2] considers that lithium chloride is a superior dehumidifying agent for the following reasons: It is one of the most hygroscopic of all inorganic compounds; it has a greater drying rate than calcium chloride; it is non toxic; it has a low freezing point and the material which separates out of a concentrated solution is either di- or mono-hydrate which allows enough liquid to remain to prevent solidification; a concentrated solution will not become entirely solid until it has been cooled below —60° F.; corrosion with lithium chloride is considered to be less than with calcium chloride but no data are given to support this claim; boiling of lithium chloride does not hydrolyze the salt.

A typical example of the flow cycle of a liquid absorption dehumidification plant is as follows: Wet gas is delivered through a liquid-separating chamber to the bottom of one or more contacting vessels where it passes upward through the contacting trays. Fresh solution is pumped through a liquid-to-liquid heat exchanger and thence to a water cooler and into the top tray of the contacting vessel. It flows from the base of the contactor to a surge tank, back through the liquid-to-liquid heat exchanger, thence through a steam preheater and into the feed plate of a stripping still. The solution is heated by means of steam coils in a reboiler. When glycerine is used, the steam heat is supplemented by allowing a stream of natural gas to pass through the heated solution and thus lower the reboiler temperature. This prevents decomposition of the glycerine. The water in the heated solution is vaporized and passes upward through the trays of the still where it is stripped of all hygroscopic material and is finally vented from the top of the still. The hot solution in the reboiler is then returned to the heat exchanger and the above cycle is repeated.

Solid Absorbents

Solid calcium chloride is sometimes used for the partial dehydration of gas at individual wells in the field. The Solvay Company[11] has described a practical method of application wherein it is recommended that the contactor be filled with calcium chloride lumps which are 1 to 2 inches in diameter. Granular or flake calcium chloride is not recommended because of the tendency of the grains to weld together under the effects of water vapor and thus cause channeling or even complete stoppage of the gas flow. The outlet gas will be in hygrometric equilibrium with the saturated solution of calcium chloride at the temperature prevailing at the top of the chloride bed.

Lump potassium hydroxide, applied in approximately the same manner as lump $CaCl_2$, has proved very successful in the removal of moisture from liquefied petroleum gases that are subjected to extremely low temperatures. Solid potassium hydroxide is more efficient than solid calcium chloride.

Solid Adsorbents

Solid drying agents that depend upon a physical attraction between the adsorbent and the condensate, may be used for practically complete removal of water vapor. Shively[9] considers that the inherent advantages of solid adsorbent agents are great enough to warrant a considerable application of this type of material, e.g., the relatively small quantity of adsorbent required for the treatment of high-pressure natural gas makes possible an economical design of a dehydration plant. Where complete dehydration is not required, some wet gas may be permitted to bypass the dehydrator and thus increase the capacity of the unit. In designing a plant of this type, means should be provided for the removal of lubricating oil or absorption oil from the gas before entering the dehydrator vessel since it appears likely that oil will impair the efficiency of the adsorbent agent.

Raay[8] has described the operation of a silica gel adsorbent plant that has been in successful commercial operation in Venezuela for several years. This plant operates at a pressure of 353 pounds per square inch and treats 8828 MCF per day. This plant consists of three contacting vessels or adsorbers and one heater. The operating cycle consists of the adsorbing period, the heating period and the cooling period. Wet gas enters the top of the first contacting vessel and leaves it at the bottom. When the adsorbent material has become saturated, the wet gas stream is switched to the second contactor. Hot gas (329° F.) from the heater then enters the bottom of the first contactor and leaves it at the top. After all of the water vapor has been removed, a stream of cooled dry gas is passed through the adsorbent bed until normal operating temperatures are obtained. The entire cycle is carried out under full operating pressure.

Literature Cited

[1] Baker, H. M. and Partridge, J. W., Oil & Gas Journal, April 13, 1939, pp. 50, 53.
[2] Bichowsky, F. R., Foote Prints 8, No. 2, 1-7-35. Also Ind. Eng. Chem. 27, 879-82 (1935).
[3] Bower, J. H., U. S. Bureau of Standards Research Paper No. 649.
[4] Clark, Jno., Amer. Gas Association meeting, Natural Gas Section, Tulsa, Okla., May, 1939.
[5] Derr, R. B., Ind. Eng. Chem. 30, 384 (1938).
[6] Gordon, David and Ryan, R. W., U. S. 1,866,560 (1928).
[7] Hammond, W. A., Chemical Education 12, No. 9, p. 445.
[8] Raay, H. De, Petroleum Engineer, Aug., 1939, pp. 45, 48.
[9] Shively, W. L., Amer. Gas Assoc. Meeting, New York, Oct., 1939.
[10] Smith, E. W., Gas World, June 7, 1930, pp. 639-50.
[11] Solvay Co., Gas World, 107, 197-201 (1939).
[12] Unpublished laboratory report of Texoma Natural Gas Company.

Elements of Vaporization and Condensation

PART V
The Utility of Phase Diagrams

By R. L. HUNTINGTON, University of Oklahoma

GRAPHICAL sketches of P-V-T and vapor-liquid relationships serve as useful tools in explaining the physical and chemical laws governing the behavior of water and the petroleum hydrocarbons. These diagrams provide the engineer with a mental picture of certain principles which cannot be readily gained by other methods of instruction. An analysis of simple chemical compounds should be undertaken before the more complex relationships involving two or more components are considered. Since water is the most common fluid on the earth, a knowledge of its properties in solid, liquid, and gaseous states is essential for all engineers.

Three Dimensional P-V-T Model for Water

I. Pressure-Volume Relationship—This graph is made by plotting isotherms (constant temperature lines) through the several phase regions, each isotherm being located in a separate (P-V) plane (Figure 1). It is difficult to present such a diagram isometrically, or in a manner which gives a third dimension depth, perpendicular to the P-V plane of the paper.

II. Vapor-Pressure or P-T Plane—The relationship between pressure and temperature is usually shown by plotting pressure as the ordinate and temperature as the abscissa, for lines of constant volume or isochores. See Figure 2. These isochores or vapor pressure curves represent the equilibrium interface or surface between two phases.

For example, the vapor pressure or sublimation curve for ice is the equilibrium line separating ice and vapor. At 32° F. this curve runs into the triple point where ice, water, and water vapor are in equilibrium at that temperature and a pressure of 14.7 pounds per square inch absolute. This point is sometimes called the non-variant since there are no degrees of freedom. This can be shown by the phase rule, there being three phases, which are equal in number to the one component plus two. The boundary between ice and water shows that the melting point of ice decreases with increasing pressure.

The vapor-pressure curve for water represents the boundary line between water and vapor up to the critical temperature and pressure. Above this critical point, the isochore is a straight line relationship for a perfect gas between pressure and temperature, the absolute pressure doubling for every two-fold increase in absolute temperature. For mixtures of two of more compounds there are two critical temperatures. These phenomena will be discussed in a later paper.

III. Isobars on the T-V Plane—This view of the three dimensional model can be gained by looking downward on it, since pressure is usually plotted as a vertical component. This relationship is used to a

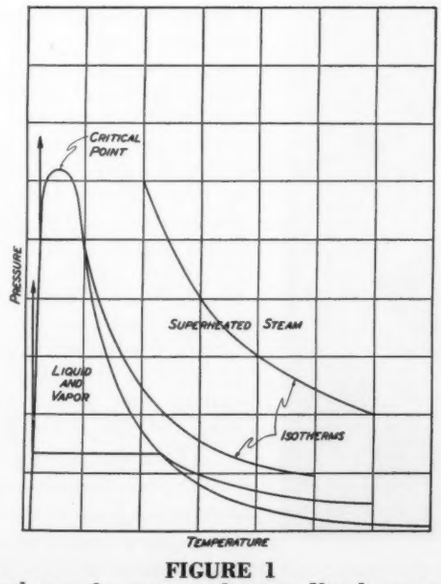


FIGURE 1
P-V Isotherms for water and steam. Not drawn to scale.

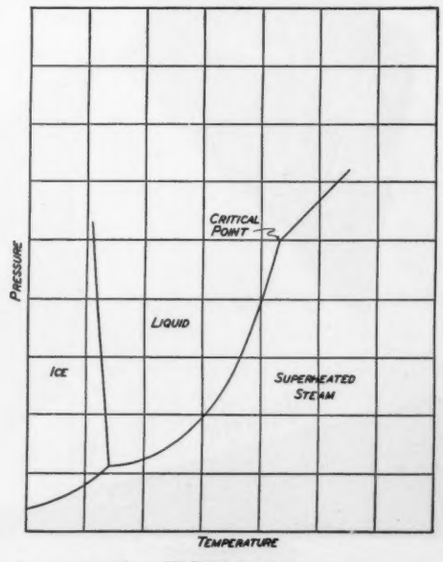


FIGURE 2
P-T Isochores for ice, water, and steam. Not drawn to scale.

smaller extent in engineering calculations than either the P-T or P-V diagrams. Figure 3 can be better understood perhaps by picturing the flow of water as it is pumped under stubstantially constant pressure of 200 pounds per square inch absolute, into a boiler, the liquid volume increasing slightly with a rise in temperature until the boiling point is reached. There is then a large increase in volume at constant temperature, this being the transition or vaporization of water into saturated steam. A further increase in temperature at 200 pounds pressure will result in a substantially two-fold volume increase for every time the absolute temperature is doubled. This latter region is known as that of superheated steam. Figure 4 is a photograph of a P-V-T plaster of paris model[2] for water in its several states. Although this model is not made to scale, it serves as a very useful tool in picturing these relationships in their three dimensions.

FIGURE 3
T-V Isobars for ice, water, and steam. Not drawn to scale.

Application of the P-V diagram to Power Generation

The petroleum engineer is interested in the available energy which may be present in a fluid such as a compressed gas or a gas-saturated liquid. The isotherm for superheated steam at 360° F. between the saturation pressure of 153 pounds per square inch absolute and 1 pound per square inch has been transferred from Figure 1 to Figure 5. The work which a pound of this steam will do in expansion between these two pressures at 360° F. can be determined by graphical integration or summation of the area under the curve, as shown by the shaded region. To keep the fundamental units consistent, the pressure is measured in pounds per square foot and volume in cubic feet, therefore the product or the area would be in feet. Since one pound of steam is being considered, the work done would be in feet times pounds or foot pounds. This area happens to be 360,000 feet and the foot pounds of work amount to $\frac{360{,}000}{33{,}000 \times 60}$ = 0.1815 horsepower hours, assuming steam to be a perfect gas in this range. If this pound of steam expands through this pressure range to 1 cubic foot in 1 hour's time 0.1815 horsepower will be exerted. In other words, power is the time rate of doing work.

Since the deviation or compressibility factor for steam is greater at high pressures than it is at the lower pressure range, the $\int pdv$ is greater than one would obtain by calculating the amount of work from the isothermal expansion of a perfect gas. In this case, the latter would yield foot pounds of work or energy:

Basis 1 cubic foot of steam

$$R \times T \times 2.3 \log_{10} \frac{153.01}{1}$$

$$\frac{1544}{18} \times (460 + 360) \times 2.3(2.184) = 354{,}000 \text{ foot pounds.}$$

This quantity amounts to 6000 foot pounds or 1.67 percent less than the actual expansion of one pound of steam as obtained by graphical integration.

The Utilization of Residue Gas for Power

For a number of years, natural gasoline plants overlooked the fact that the residue gas coming from the absorbers held within itself a vast reservoir of energy. This gas usually was brought to low pressure through reducing regulators without the recovery of any of the horsepower hours it had stored up. Today the gas-driven turbine is utilizing this expansive energy in the gas between the 50 to 60 pounds per square inch (abs.) absorber pressure, and the atmospheric exhaust pressure at which pressure level the gas can be burned as fuel. Where fuel is cheap the heating of the gas is another means of securing added power as shown by Figure 6. This practice is especially desirable for high-velocity turbines as a small amount of condensation will cause wear and "wire cutting" of the turbine blades.

Where very large volumes of excess residue gas are available, gas-water lift systems have been installed adjacent to water-cooling towers. Although the expansion

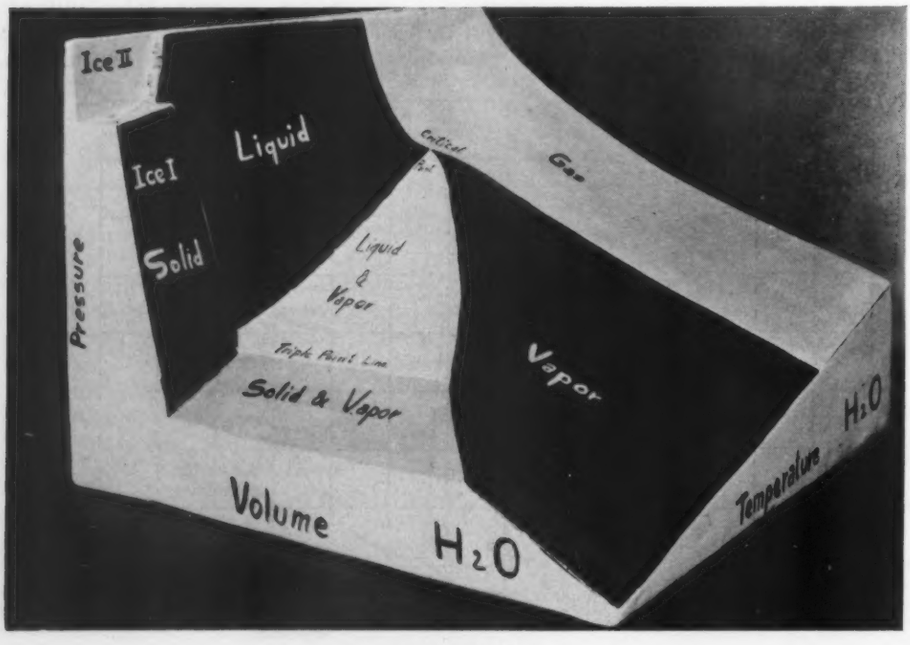


FIGURE 4
P-V-T Model for H_2O (Not drawn to scale).

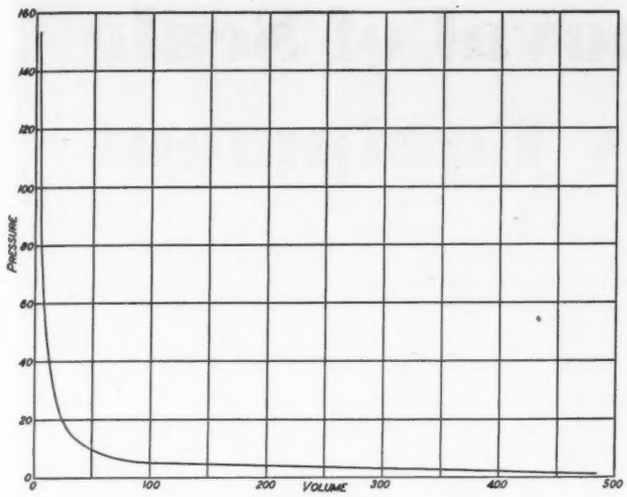


FIGURE 5
Isothermal Expansion of Steam at 360° F. Work performed equals area under curve.

efficiency of such a lift system may not be as high as that of a turbine, the lower initial investment makes the installation of the vertical pipes highly desirable. By referring to Figure 7 it is seen that the water submergence is at least as much as the water head above the surface of the coil pit or "water well."

Calculation of the Efficiency of a Gas-Water Lift

For the isothermal expansion of a perfect gas the integrated value of the expansive work, $\int PdV$, is expressed as $RT1n\frac{V_2}{V_1}$. This formula is obtained through integrating the PdV term by substituting $P = \frac{RT}{V}$ from the perfect gas law. A pound molecular weight of any gas expanding from one volume to two volumes at 60° F. or 520° R would be:

$$R \times T \times 1n_e \frac{V_2}{V_1} = 2.3\ R\ T \log_{10} \frac{V_2}{V_1}$$

$$1544 \times 520 \times .692 = 550{,}000 \text{ foot pounds}$$

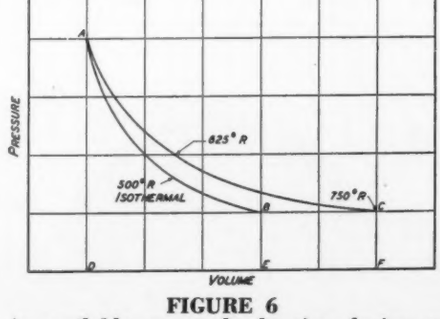


FIGURE 6
Increase in available energy by heating during expansion.

From this equation it is easily seen that 16 pounds of methane (CH_4) gas or 1 pound molecular weight will give up as much energy as 30 pounds of ethane (C_2H_6) or 2 pounds of hydrogen (H_2). If gas were bought on a weight basis, the lower the molecular weight of the gas, the more valuable it would be for gas-lift purposes.

Another form of this isothermal equation for a perfect gas is given in the form:

$RT\ 1n\ P_1/P_2$, since volumes are inversely proportional to absolute pressures. The same amount of work can be obtained from a gas expanding from 1000 pounds to 100 pounds as there is available from 100 pounds down to 10 pounds per square inch absolute. By heating a gas from 100° F. to 200° F. the amount of work obtainable is increased by the ratio of the absolute temperatures.

$$\frac{200 + 460}{100 + 460} = \frac{660}{560} = 1.18$$

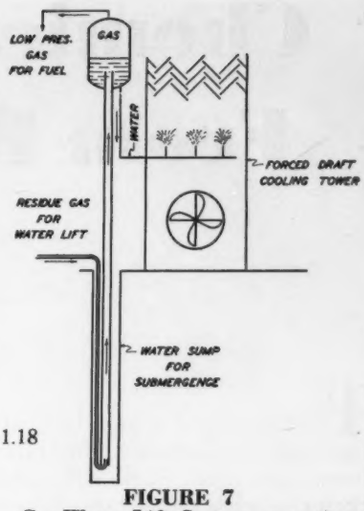


FIGURE 7
Gas-Water Lift System operating in conjunction with cooling tower.

A certain cooling tower of the atmospheric type has a capacity of 10,000 gals of water per minute. The water must be lifted 55 feet in height since the tower is 40 feet high. This 15 foot head is needed to give proper distribution to the spray nozzles and headers. How many standard cubic feet of residue gas of the following composition:

Basis—100 lb. mols

	Vol %	Mol %	100 mols	lbs / mol	lbs / 100 mols
Methane	80	80	80 ×	16 =	1280
Ethane	15	15	15 ×	30 =	450
Propane	5	5	5 ×	44 =	220
					1950

will be required to lift the water per 24 hour day?

If the absorbers are operating under 50 pounds per square inch absolute and the gas-water separator at the top of the lift tower is to be 16 pounds absolute, the calculation can be made as follows, based on isothermal expansion at 60° F. or 520° F. absolute.

$$2.3\ R \times T \times \log_{10} P_1/P_2$$

or $2.3 \times 1544 \times 520 \times \log_{10} 50/16 = 910{,}000$ foot pounds of work per pound mol or 380 std cubic feet of gas one pound mol of gas would lift $\frac{910{,}000}{55}$ = 16,500 pounds of water since each pound of water is to be elevated 55 feet in height. Each standard cubic foot of gas would lift $\frac{16{,}500}{380}$ = 43.5 pounds of water. There are $10{,}000 \times 8.33 \times 24 \times 60 =$ 120,000,000 pounds of water to be circulated per day, therefore $\frac{120{,}000{,}000}{43.5}$ = 2,760,000 standard cubic feet of gas will be required per day, based on 100 percent lift efficiency.

It has been found by Cromer et al[1] that lift efficiencies for an air-water column vary from 0 to 42 percent. If the above gas lift system has an efficiency of 40 percent, the gas requirement will be $\frac{2{,}760{,}000}{0.4}$ = 6,920,000 cubic feet per day. The saving in kilowatt hours at 1.0 cent per KW hour will amount to:

$$\frac{120{,}000{,}000 \times 55 \text{ ft. lbs.} \times .746 \text{ K.W./H.P.} \times .01}{33{,}000 \times 60 \text{ ft. lbs./H.P. hr.} \times .8 \text{ 80\% efficiency}} = \$31.00 \text{ per day savings in electrical energy.}$$

Literature Cited

[1] Cromer, S. and Huntington, R. L. A.I.M.E., Petr. Tech. T.P. 1080 August, 1939.
[2] Welch Company, W. M. Chicago, Illinois.

Chemical Removal of Scale From Refinery Equipment

By L. W. LEE, Dowell Incorporated

THE standard scale removal practice in the past has been by mechanical methods. Numerous attempts have been made during the past many years to supplement with chemicals this method of removal of industrial scale deposits in heat exchangers, cooling coils, condensers, internal-combustion-engine cooling jackets and other types of refinery equipment. The results have varied and occasionally have been unsatisfactory.

During the last several years, improvements have been made in methods of reducing and preventing the normal corrosive action of acid solutions now widely used in oil-well treating. These methods can and are being appropriately modified and successfully applied to eliminate corrosion in industrial chemical scale removal work. With the serious corrosion problem overcome, the refining and other industries welcomed the use of chemical methods to remove the scale deposits that were causing serious delays in production schedules, costly shutdowns for repairs, and subnormal efficiency with its resultant higher operating costs.

Chemical methods for removing scale deposits have proven so effective that large refineries are adopting this new type of service for periodical scale removal. During the last year some difficult scale removal projects have been successfully accomplished on heat exchangers, economizers, oil pipe lines, submerged cooling jackets, vacuum condensers, cooling jackets on large booster pumps and compressors and Diesel engines.

Scale Analysis

To be assured of successful results by chemical treatment, it is necessary to know the exact composition of the scale which is to be removed. The usual practice is to make a preliminary test by the use of portable kits used in determining solubility. If the scale is not dissolved sufficiently to ensure proper treatment, a sample is sent to an X-Ray laboratory for complete identification. The X-Ray powder diffraction method for the quantitative identification of the chemical composition of crystalline materials has been used commercially for some time past by The Dow Chemical Company.[1]

The method consists of obtaining a pattern of an unknown crystalline substance and resolving the lines of this pattern by comparison with those obtained from known compounds. The same crystalline material always gives the same pattern, which is different from that obtained from any other crystalline material.

Treatment Procedure

After the analysis of the scale has been made and the solvent best suited for its removal has been selected, a tank truck, equipped with pumps and steam heater and carrying basic and auxiliary chemicals, is used to introduce the materials into the equip-

[1] Hannawalt, J. D., Rinn, H. W. and Frevel, L. K. Chemical Analysis by X-Ray Diffraction. Industrial and Engineering Chemistry (Analytical Edition) p. 457. Sept. 15, 1938.

FIGURE 1

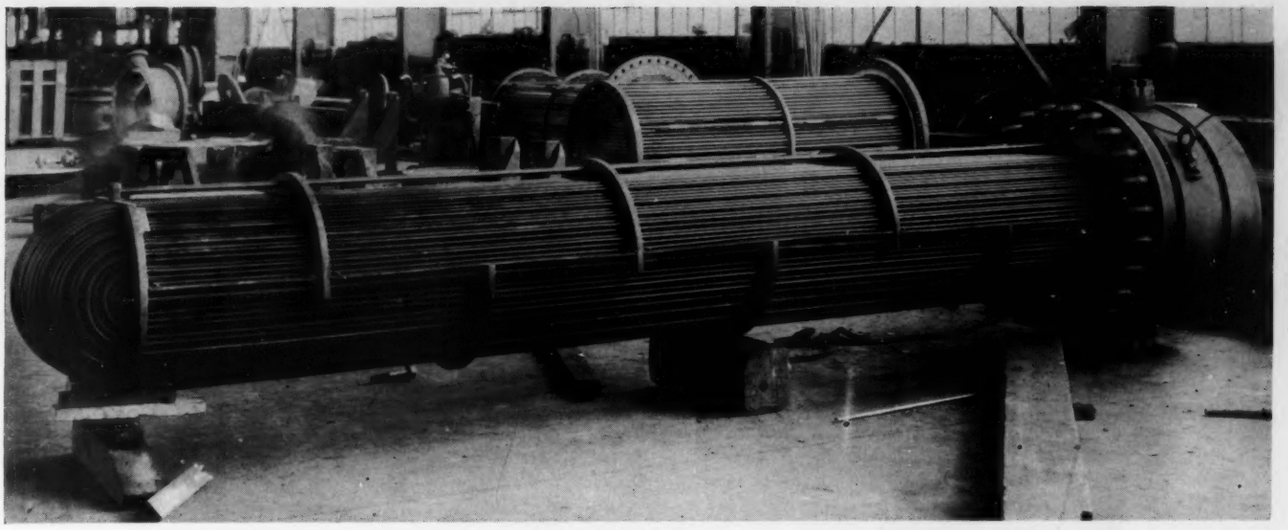


FIGURE 2

ment. The solvent base is modified by various additive agents, catalysts, intensifiers, and inhibitors.

The usual practice is to have the equipment prepared for cleaning by plant personnel under supervision of the service company. This prevents loss of time and permits a more rapid return of the equipment to service. Often the scale is removed completely in a few hours. In severe cases, where large amounts of scale are present, it is necessary to allow the equipment to stand over-night and in some instances as long as 24 hours. It is the usual practice to agitate the solvents in the vessels as this produces more rapid scale removal. Generally this agitation is secured by circulating the solvent through the vessel by means of pumps mounted on the service company's trucks.

So far scale-removal jobs have not necessitated an equipment shutdown of more than 36 hours. The manner of introduction of the scale-removing solvent is very important; best results have been obtained by introducing fresh solvent into the vessel to be serviced by as many avenues as possible. Ordinarily the unit to be de-scaled is filled through lower connections especially selected for this particular treatment. Pumping is continued and the solvent overflowed and allowed to return to the truck tank and circulation maintained for a definite period. Circulation keeps fresh solvent in contact with the exposed scale while soaking gives time for the solvent to do its work in inaccessible crevices and bends. The ability to wash out all the solvent prevents any contamination of products. Many scale deposits on the outside of exchanger tubes are difficult to remove mechanically and impossible to clean thoroughly. Illustrations showing two types of such tube bundles are shown in Figures 1 and 2.

A revolutionary departure from the conventional design of heat exchangers is the newly developed spine tube heating surface as shown in Figure 3. This construction has as much as 20 times the external area of a bare tube of the same inside diameter. Spine tubes are now being applied to shell-and-tube type exchangers and to double-pipe type exchangers. The removal of scale and sludge from this

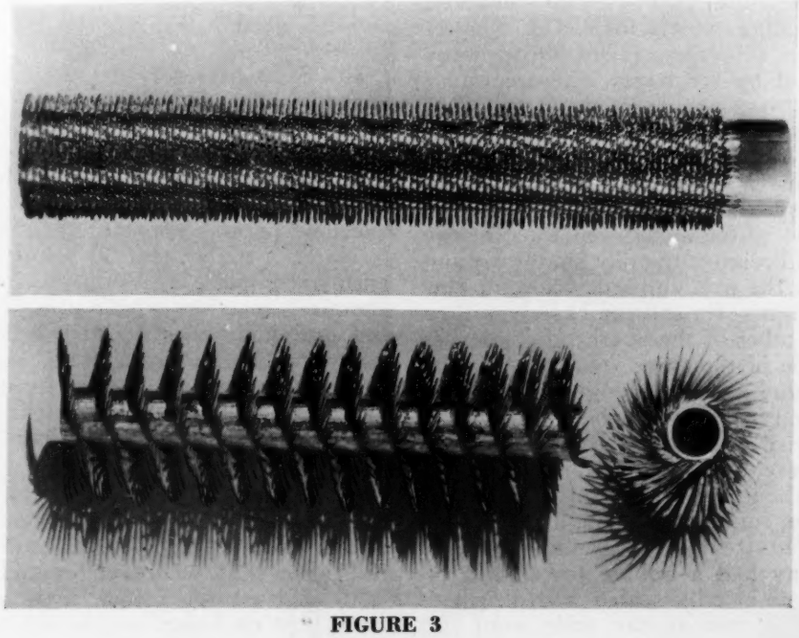


FIGURE 3

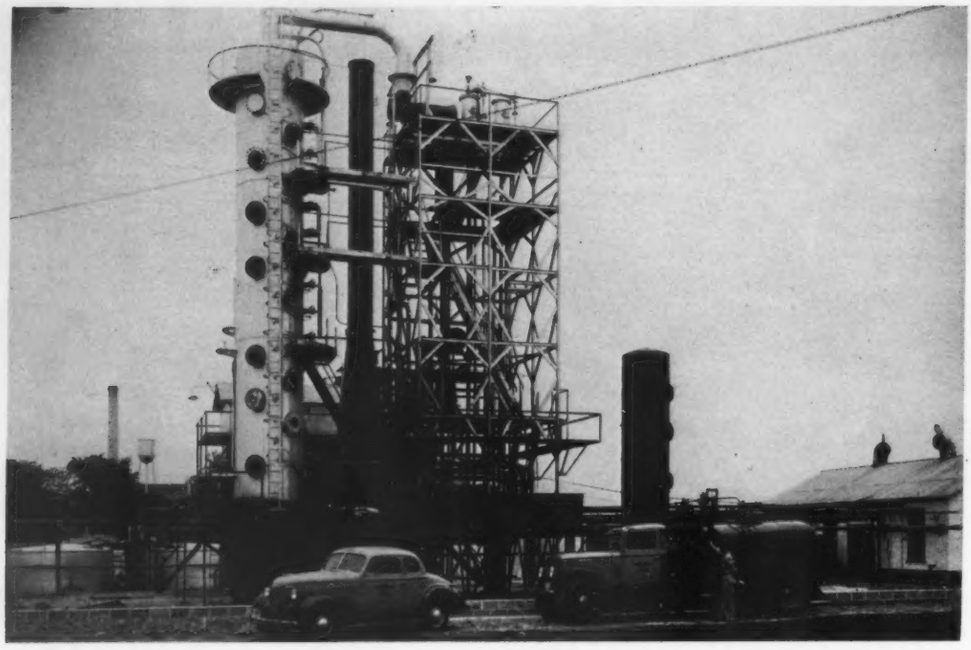


FIGURE 4

type of equipment is greatly facilitated by the use of chemical solvents.

Midwestern Oil Refinery Treatment

In one instance the heat exchange equipment for a complete cracking and stabilizing unit in a large Midwestern refinery was successfully cleaned by chemical methods. The equipment consisted of one water-cooled overhead condenser with scale on the inside of the tubes, three shell-and-tube steam generators with scale on the outside of the tubes, and two heat exchangers. While on stream, the heavy ends from the bottom of the bubble tower were cooled on the shell side of two heat exchangers in this system and during this operation a coating of hard black scale, consisting of 75 percent iron sulphide and 25 percent silicon dioxide, was deposited on the outside of the tubes. This scale was covered by a viscous oily sludge which formed a blanket preventing penetration of scale solvent. This sludge was partially removed by steaming. The treatment then proceeded as follows:

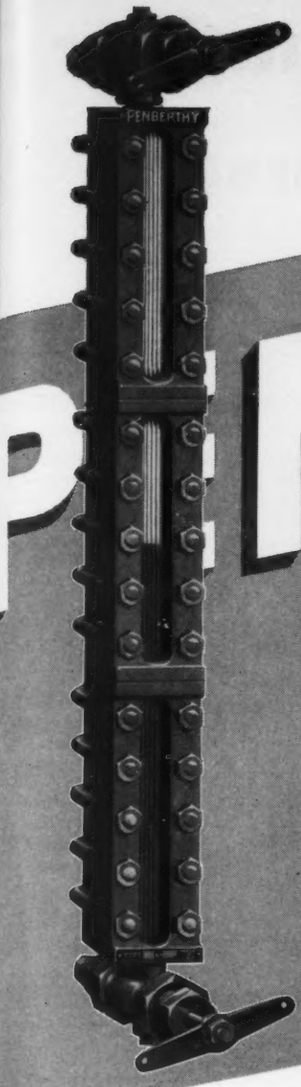
Twenty gallons of a de-oiling solvent were pumped into the shell side of each heat exchanger, steam was introduced inside the tubes until the temperature on the shell side had reached 200° F. The steam was then shut off and water introduced to condense the solvent so it would remove the oily sludge around the tubes and expose the iron sulphide scale for further treatment. Enough scale solvent base was then pumped through the tubes of the overhead condenser and into the shell side of the three steam generators to cover the tube bundles. The sludge and solvent base were then drained from the two heat exchangers which were filled with a modified base solvent at 150° F. All units were allowed to stand until the following morning when they were drained, washed, opened for inspection, found to be completely clean, and were put back on stream.

This same company had a bubble tower and reboiler system that was heavily scaled with iron sulphide. They desired to remove the scale from this system and put it into a new naphtha service. The tower was 44 feet high, 40 inches inside diameter and contained bubble plates spaced approximately 30 inches apart. As there were only three small manholes in this tower, manual cleaning presented a very difficult problem. It would have been necessary to remove all the trays in order that the inside of the shell could be sand-blasted. This was expensive and would have required a much longer time than the refinery wished to allow for the work. As this piece of equipment was urgently needed in their service run, and they would still have had to clean all connecting pipe lines, reboilers, and condensers by some method, it was absolutely necessary that the whole system be entirely free from any contamination.

Dowell Incorporated was consulted on this problem and after consultation with the refinery officials and technicians, a chemical treatment was worked out as follows:

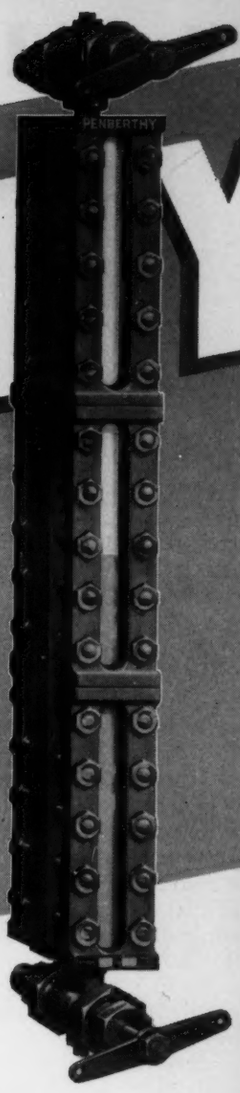
Hot industrial solvents were introduced into one of the reboilers in sufficient quantities to fill the towers and overflow through the overhead condensers and back to the truck tank. The hook-up used on this treatment can be seen in Figure 4. Periodical circulation was maintained until the strength of the overflow became constant. The solvent was allowed to stand in the system for a longer period of time to ensure complete reaction of the scale. When all chemical reaction within the system was finished, the equipment was drained, washed, inspected, and found to be free from scale, and was immediately returned to service. The time required was 36 hours, only a fraction of the time which would have been necessary if the tower trays had been dismantled and cleaned by manual means.

As a result of the satisfactory cleaning obtained by these and other refinery treatments, operators of refineries have become interested and there is every indication that, wherever practical, chemical methods will be used for future scale and sludge removal from heat exchange equipment.



PENBERTHY *Reflex*
DROP FORGED STEEL
LIQUID LEVEL GAGES

PENBERTHY
DROP FORGED STEEL
Transparent
LIQUID LEVEL GAGES



PENBERTHY LIQUID LEVEL GAGES *meet your requirements*

Liquid shows black—empty space shows white. Preferred wherever liquid level must be easily and positively visible . . . and when liquids are under high pressure or at high temperature.

All Penberthy Gages conform with A. P. I.—A. S. M. E. requirements.

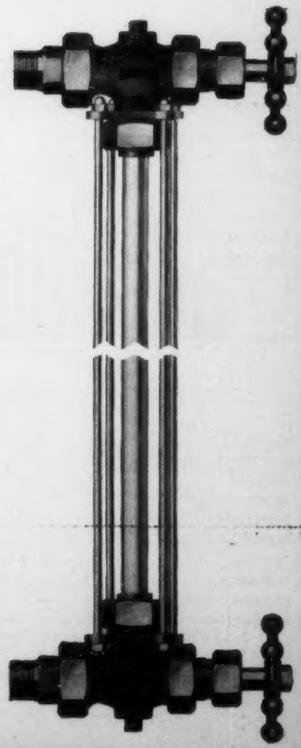
Used to observe color and density of liquids under high pressures, and/or temperatures. Construction is exceptionally rugged . . . similar to Reflex types.

PENBERTHY *Reflex*
WATER GAGE SET

Water shows black—steam shows white. U-Bolt construction is strongest and simplest to service. Glass replaced by simply removing nuts on face of gage . . . unnecessary to work between gage and boiler.

PENBERTHY
DROP FORGED STEEL
LIQUID LEVEL GAGES

Made of Chromium-molybdenum alloy temperature-resisting steel, extra heavy throughout. Stainless steel trimmed. Tubular glass type gages also available in various other metals suitable for practically all conditions.



PENBERTHY INJECTOR CO.

DETROIT, MICHIGAN • **Canadian Plant; Windsor, Ontario**

PENBERTHY PRODUCTS

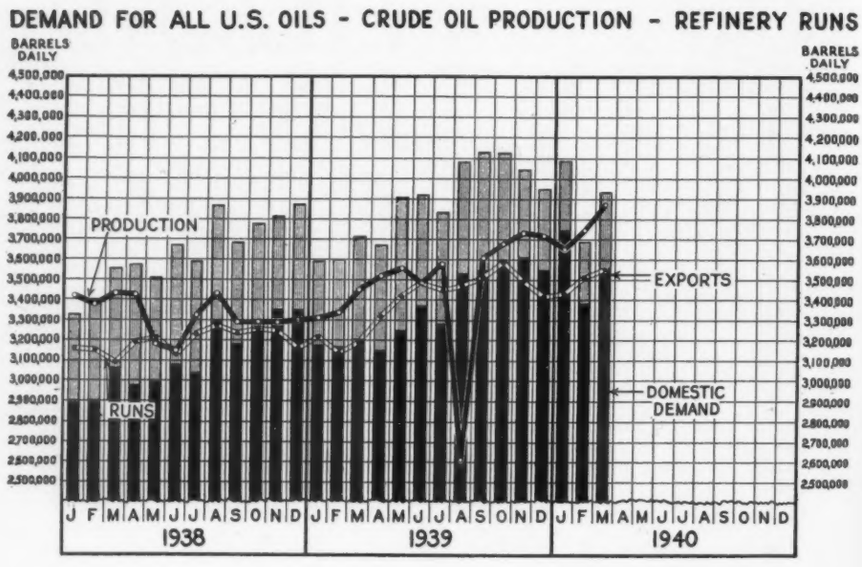
Surplus Gasoline and Smaller Exports Handicap Industry

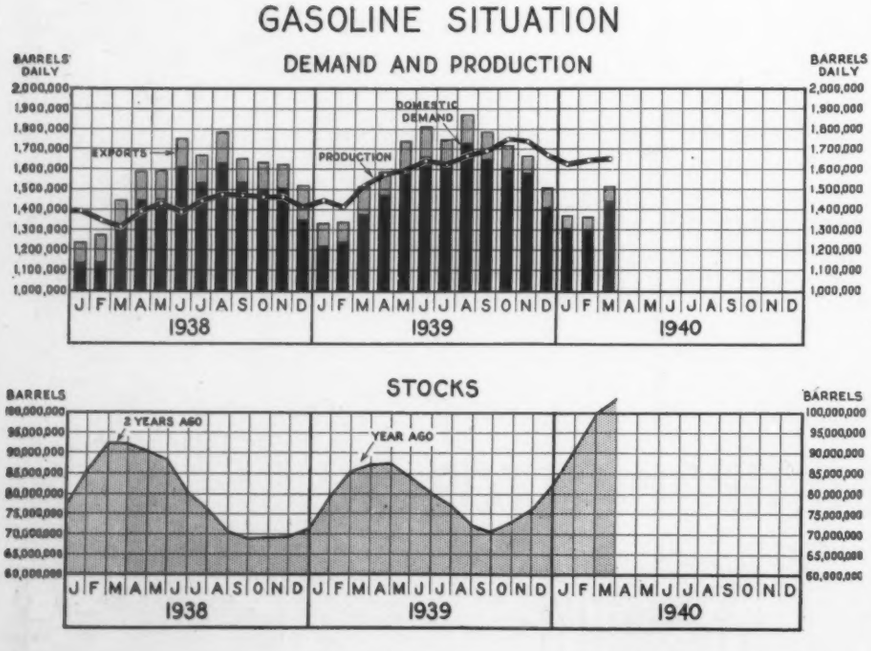
By L. J. LOGAN

CONDITIONS in the oil industry have become progressively less satisfactory since the beginning of this year, and unfavorable developments have been emphasized in the past several weeks by declines in prices of crude and refined oils.

Confronted with a "strange" war abroad, which has not conformed with any preconceived patterns, and with a resultant uncertain domestic situation, the industry has been handicapped by exceptional difficulty in planning its operations and in controlling its inventories.

Whereas the European war originally was expected to stimulate exports of oils, it actually has caused a sharp curtailment of shipments. Domestic business in general expanded greatly after outbreak of the war, but it went into the new year on a downtrend that has not yet definitely changed. And the oil industry's business, as usual, ultimately has had to fit into the general picture. Markets that were firm as the year opened finally weakened, as rising curves of domestic demand flattened, with mills and factories slowed-down and using somewhat less fuel and lubricants, and with employment and consumer purchasing power thereby somewhat curtailed.


DEMAND FOR ALL U.S. OILS - CRUDE OIL PRODUCTION - REFINERY RUNS
BARRELS DAILY
PRODUCTION
EXPORTS
RUNS
DOMESTIC DEMAND
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D
1938
1939
1940

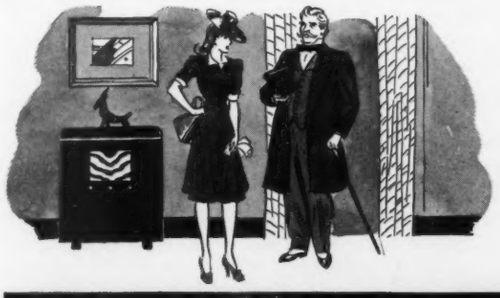

GASOLINE SITUATION
DEMAND AND PRODUCTION
BARRELS DAILY
EXPORTS
PRODUCTION
DOMESTIC DEMAND
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D
1938
1939
1940
STOCKS
BARRELS
2 YEARS AGO
YEAR AGO
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D
1938
1939
1940

Meanwhile, special circumstances have added complications for the oil industry. The coldest winter for years, coupled with sharply increased numbers of oil burners in use, resulted in scarcity of light fuel oils east of California; and the industry was obliged to boost refinery output of that product to proportions that required surplus production of gasoline, which accumulated in storage and became a burden that still must be carried. From the rushing business in heating oil the industry has inherited an extremely weak market for gasoline, present prices of that principal product being among the lowest on record, as unprecedented stocks threaten to prolong unsatisfactory market conditions.

Over-refining and surplus production of gasoline have been encouraged this year, moreover, by the production of crude oil in excess of current market requirements. There has been overproduction of crude not only in unprorated Illinois but also in some of the prorated states, where allowables have been set substantially above indicated demand. In the first four months of this year, 20,000,000 bar-

GIBSON GIRL—1940 MODEL

Suppose someone who lived forty or fifty years ago—say one of the founders of Mathieson—could pay us a visit today. And suppose we could have the pleasure of showing him the sights of 1940, of explaining the vast changes that have taken place since the turn of the century. What do you think would amaze the old gentleman most? If he were one of the pioneers who founded Mathieson, we believe he would be most interested in the revolutionary changes wrought by chemical progress and in the part his successors have played in building the present-day America. We would go about telling him the story as we tell it in this series of advertisements.



● Ah, Mr. M., so you recognize that silken rustle! But it's more than a petticoat—our 1940 Gibson Girl wears the material from the skin out. And we'll tell you another secret. It's not actually silk at all—it's rayon, the remarkable new synthetic fabric that is clothing American women of today with new elegance and enabling the humblest shopgirl to dress with a chic attainable in your day only by wealthy girls.

And you'll be interested, Mr. M., to know that the men who followed you at Mathieson have played a vital part in this and other modern developments in the textile field — pioneering time and again in the production and distribution of better, more economical raw materials — for this and other great American industries.

MATHIESON CHEMICALS

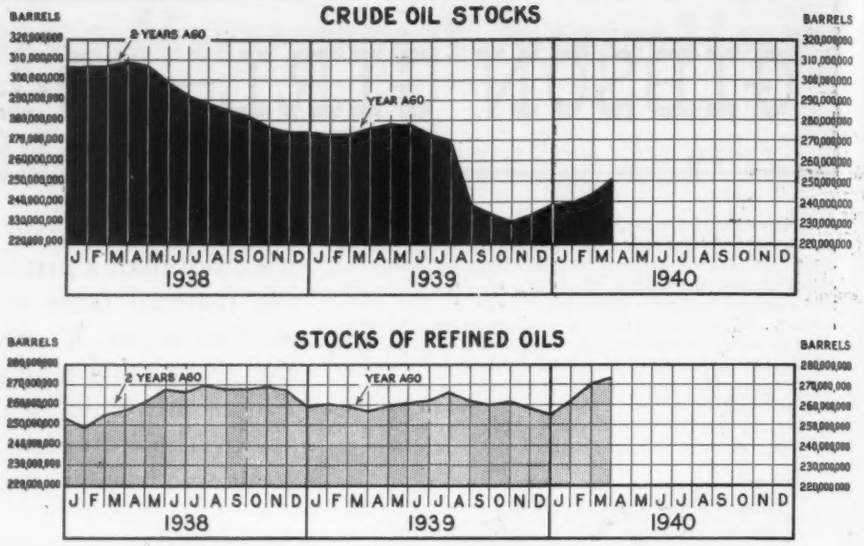
SODA ASH . . . CAUSTIC SODA . . . BICARBONATE OF SODA . . . LIQUID CHLORINE . . . BLEACHING POWDER . . . HTH PRODUCTS . . . AMMONIA, ANHYDROUS and AQUA . . . FUSED ALKALI PRODUCTS . . . SYNTHETIC SALT CAKE . . . DRY ICE . . . CARBONIC GAS . . . ANALYTICAL SODIUM CHLORITE

THE MATHIESON ALKALI WORKS (INC.)
60 E. 42ND STREET, NEW YORK, N. Y.

rels of crude oil accumulated in storage, despite the charging of record-breaking quantities to refinery stills. And naturally, the large supplies available at wells were conducive to excessive runs.

Fortunately for the economic welfare of the industry, the restrictions on crude production lately have been tightened, allowables having been made stricter in May and even more so in June. Consequently, surplus crude production no longer is a handicap.

Some constructive effort is being put forth, also, toward alleviating the burden of surplus gasoline stocks, the remedy that is being applied being the taking of exceptionally low yields of gasoline from crude at the refineries and the stepping up coincidentally of yields of light fuel oils, in precaution against scarcity of those oils again next fall and winter. In March, 1940, latest month for which figures are available, the average yield of gasoline was down to 42.2 percent, compared with 44.4 percent in March, 1939; and the average yield of gas oil and distillate fuel oil was up to 14.8 percent, compared with 13.7 percent in March, 1939.


CRUDE OIL STOCKS
BARRELS
2 YEARS AGO
YEAR AGO
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D
1938
1939
1940
STOCKS OF REFINED OILS
BARRELS
2 YEARS AGO
YEAR AGO
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D
1938
1939
1940

Oil Demand Up in 1940 Despite Smaller Exports

Figures indicate barrels, and are from Bureau of Mines

	MARCH			FIRST THREE MONTHS		
	1939	1940	Percent Change	1939	1940	Percent Change
SUMMARY—						
Total Demand	116,747,000	121,997,000	+ 4.4	330,140,000	355,821,000	+ 7.8
Daily average	3,766,000	3,935,000	+ 4.4	3,668,000	3,910,000	+ 6.6
Exports:						
Crude petroleum	4,966,000	4,046,000	— 18.5	14,253,000	11,575,000	— 18.8
Refined products	10,849,000	7,583,000	— 30.1	26,678,000	20,074,000	— 24.8
Total exports	15,815,000	11,629,000	— 36.5	40,931,000	31,649,000	— 22.7
Domestic Demand:						
Total domestic demand	100,932,000	110,368,000	+ 9.3	289,209,000	324,172,000	+ 12.1
Daily average	3,256,000	3,560,000	+ 9.3	3,213,000	3,562,000	+ 10.8
TOTAL DEMAND FOR PRODUCTS						
Motor Fuel:						
Domestic	42,520,000	44,607,000	+ 4.9	114,882,000	122,534,000	+ 7.7
Exports	4,336,000	2,265,000	— 47.8	10,883,000	6,442,000	— 40.8
Total	46,856,000	46,872,000	+ 0.03	125,765,000	128,976,000	+ 2.6
Aviation Gasoline (included above):						
Domestic	*	427,000	.....	*	1,337,000	.....
Exports	392,000	249,000	— 36.5	1,127,000	529,000	— 53.1
Total	.....	676,000	.....	.....	1,866,000	.....
Kerosene:						
Domestic	5,201,000	6,273,000	+ 20.6	17,082,000	20,178,000	+ 18.1
Exports	546,000	485,000	— 11.2	1,888,000	1,174,000	— 37.8
Total	5,747,000	6,758,000	+ 17.6	18,970,000	21,352,000	+ 12.6
Gas Oils & Distillate Fuels:						
Domestic	13,923,000	16,494,000	+ 18.5	45,653,000	57,211,000	+ 25.9
Exports	2,924,000	2,318,000	— 20.7	6,730,000	5,101,000	— 24.2
Total	16,847,000	18,812,000	+ 11.7	52,383,000	62,312,000	+ 18.9
Residual Fuel Oils:						
Domestic	28,436,000	30,881,000	+ 8.6	82,468,000	89,845,000	+ 8.9
Exports	2,047,000	932,000	— 54.5	4,351,000	2,840,000	— 34.7
Total	30,483,000	31,813,000	+ 4.4	86,819,000	92,685,000	+ 6.8
Lubricants:						
Domestic	1,987,000	1,883,000	— 5.2	5,249,000	5,459,000	+ 4.0
Exports	829,000	1,193,000	+ 43.9	2,360,000	3,350,000	+ 41.9
Total	2,816,000	3,076,000	+ 9.2	7,609,000	8,809,000	+ 15.8
Wax (thousands of pounds):						
Domestic	20,495,000	19,343,000	— 5.6	68,303,000	71,558,000	+ 4.8
Exports	26,384,000	25,642,000	— 2.8	63,887,000	75,051,000	+ 17.5
Total	46,879,000	44,985,000	— 4.0	132,190,000	146,609,000	+ 10.9
Coke (short tons):						
Domestic	129,200,000	119,900,000	— 7.2	356,300,000	383,400,000	+ 7.6
Exports	9,800,000	13,700,000	+ 39.8	28,400,000	35,800,000	+ 26.1
Total	139,000,000	133,600,000	— 3.9	384,700,000	419,200,000	+ 8.9
Asphalt (short tons):						
Domestic	230,700,000	254,200,000	+ 10.2	575,100,000	547,000,000	— 4.9
Exports	2,700,000	18,900,000	+ 600.0	13,500,000	62,300,000	+ 36.1
Total	233,400,000	273,100,000	+ 17.0	588,600,000	609,300,000	+ 3.5
Road Oil:						
Domestic	228,000	111,000	— 151.3	581,000	311,000	— 46.5
Miscellaneous:						
Domestic	187,000	123,000	— 34.2	513,000	398,000	— 22.4
Exports	9,000	123,000	+1300.0	22,000	377,000	+1613.6
Total	196,000	249,000	+ 27.0	535,000	775,000	+ 44.9

* Figures not available.

Similarly, the yields of gasoline in February and January of this year were materially lower than in the corresponding months a year previously, while the yields of light fuel oils were substantially larger.

An accompanying table shows how the yields of gasoline in the first three months of this year compared with those in corresponding months of other recent years, and also how the yields have run in the remaining months of each year.

	Percent Yield of Gasoline			
Month—	1937	1938	1939	1940
January	43.2	44.1	44.8	42.9
February	45.0	42.8	45.0	42.4
March	44.5	42.6	44.4	42.2
April	44.6	43.6	44.8	...
May	43.9	44.2	44.4	...
June	43.5	44.3	44.5	...
July	43.2	44.7	44.5	...
August	43.2	44.1	45.1	...
September	45.3	45.3	45.1	...
October	44.6	44.9	45.3	...
November	44.0	45.0	45.8	...
December	43.9	44.4	45.0	...
Year	43.9	44.3	44.9	...

Also tabulated herewith are the yields of light fuel oils in the first three months of this year and in every month of other recent years.

	Percent Yield of Gas Oil and Distillate Fuel Oils			
Month—	1937	1938	1939	1940
January	14.1	14.2	14.2	15.5
February	13.2	13.8	14.6	16.0
March	11.7	12.8	13.7	14.8
April	11.4	12.1	13.4	...
May	11.1	12.2	11.7	...
June	11.2	11.5	12.9	...
July	12.1	12.7	11.9	...
August	11.9	12.5	12.3	...
September	12.3	13.5	12.3	...
October	12.9	13.7	13.5	...
November	13.3	13.1	13.1	...
December	13.8	14.2	13.6	...
Year	12.4	13.0	13.1	...

These figures show that the industry has been achieving a degree of success in adjusting yields of

SAFELY CONTROLS

1000 lb. pressures at 1000 degrees F.

NICKEL ALLOY STEELS

Cast from Nickel alloy steel by the Sivyer Steel Casting Co., Milwaukee, the floating tube heads pictured above are being pressure tested. Nickel alloy steels retain strength and toughness from below minus 100 degrees Fahrenheit to above 1000 degrees. Furthermore, the low creep rate of Nickel-chromium-molybdenum steels and certain other nickel alloy steels is an added advantage in refinery applications involving high temperatures. These Nickel-chromium-molybdenum steel castings will be used in refinery service to withstand 1000 lbs. pressures and 1000 degrees F. temperatures.

NICKEL STEELS...

widely used for these Refinery Applications:

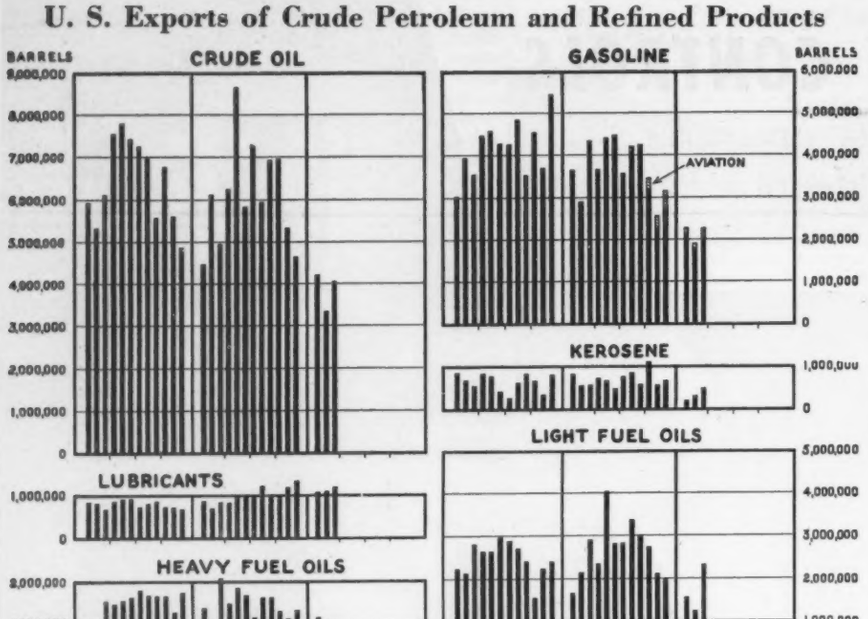
EXCHANGERS	VALVE BODIES	STRESSED BOLTS
CONDENSERS	PRESSURE VESSELS	PIPING CORROSIVES
COOLERS	RETURN BENDS	DEWAXERS
	TUBE SUPPORTS	

• Whether your problem is corrosion, breakage or temperture extremes, your consultation is invited on refinery applications best served by materials containing Nickel.

Dense-grained, uniformly pressure-tight, these high-strength Nickel alloy steel castings permit simplified design. One casting replaces eight pieces required with former types of construction. Tests on a typical heat showed a tensile strength of 106,750 lbs. per sq. in. (elongation in 2", 22%). Refiners specify metals strengthened and toughened with Nickel to assure longer, improved service life in their equipment.

THE INTERNATIONAL NICKEL COMPANY, INC. 67 WALL STREET NEW YORK, N. Y.

U. S. Exports of Crude Petroleum and Refined Products



products into better relationship to the market requirements for those products.

Weekly statistics for more recent periods also have evidenced effectiveness of efforts toward bringing about a better over-all inventory situation for the industry. Gasoline stocks gradually are being reduced, although more slowly than desirable; and fair results are being obtained in building up stocks of light fuel oils. In February, 1940, stocks of those oils were reduced 16 percent below the level of February, 1939. But now the supplies are about 6 percent larger than a year ago, having broken above the 1939 trend a few weeks ago. Petroleum economists have advised, however, an extension of special efforts toward building up the stocks of the light fuel oils this summer more than normally; having suggested as economically desirable an inventory of about 48,000,000 barrels on September 30, an increase of about 25 percent over the 38,000,000 barrels held on September 30, 1939.

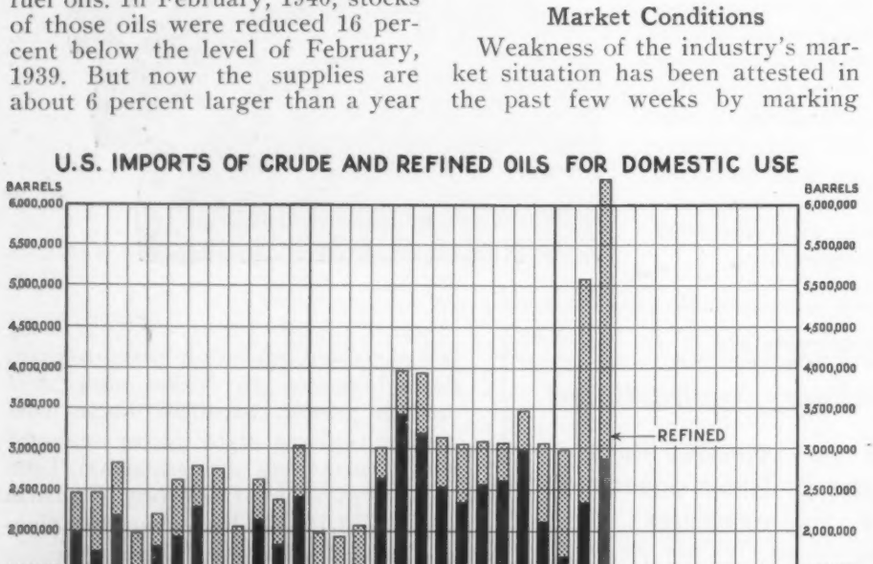
Market Conditions

Weakness of the industry's market situation has been attested in the past few weeks by marking down of prices of both crude and refined oils. The gasoline market has become further unsettled, and wholesale and retail prices have been lowered in nearly all sections of the United States. Consequently, present prices are even lower than the depressed prices of a year ago. Retail prices of gasoline were reduced drastically throughout the Pacific Coast region May 28, and there have been reductions of service station postings also in the Southwest and other districts lately, while wholesale markets have continued unsteady, with prices extremely low.

The weak gasoline market on the Pacific Coast caused general adoption recently of the lower crude prices initiated in California February 1 by two major purchasers, although the original reductions were based on depressed prices of fuel oils on the West Coast.

Still around 100,000,000 barrels, gasoline stocks in the United States as a whole apparently embody a

U.S. IMPORTS OF CRUDE AND REFINED OILS FOR DOMESTIC USE



Changes From Year Ago in Stocks of Crude and Refined Oils in the United States

(Figures indicate barrels)

LATEST WEEKLY DATA

(Sources: Crude Stocks, Bureau of Mines; all other figures American Petroleum Institute)

STOCKS OF:	June 3 1939	June 1 1940	Percent Change
Gasoline	84,070,000	100,353,000	+19.4
Gas Oil & Distillate	27,949,000	29,533,000	+ 5.7
Residual Fuel Oil	111,282,000	104,768,000	− 5.9
Crude Oil	[1]278,289,000	[2]259,330,000	− 6.8

LATEST MONTHLY DATA

ITEM	Stocks at End of March 1939	1940	Percent Change
SUMMARY—			
Crude Petroleum:			
Refinable in U. S.	276,355,000	251,120,000	−19.1
Heavy in Calif.	15,814,000	13,485,000	−14.7
Natural Gasoline	4,721,000	5,393,000	+14.2
Refined Products	266,342,000	273,845,000	+ 2.8
Total, all oils	563,232,000	543,843,000	− 3.4
Days' supply: March basis	150,000	138,000	−18.0
PRODUCTS—			
Gasoline:			
Finished	81,189,000	96,467,000	+18.8
Unfinished	5,932,000	7,243,000	+22.1
Total	87,121,000	103,710,000	+19.0
Kerosene	5,605,000	4,114,000	−26.6
[3]Gas Oil & Distillate Fuels	20,115,000	18,541,000	− 7.8
[3]Residual Fuel Oils	89,768,000	84,115,000	− 6.3
Lubricants	7,800,000	8,084,000	+ 3.6
Wax (thousands of pounds)	117,537,000	90,373,000	−23.1
Coke (short tons)	694,000,000	624,000.000	−10.1
Asphalt (short tons)	650,000,000	699,000,000	+ 7.5
Road Oil	907,000	924,000	+ 1.9
Miscellaneous	235,000	368,000	+56.6
Other Unfinished Oils	38,216,000	36,920,000	− 3.4

[1] Stocks, May 27, 1939.
[2] Stocks, May 25, 1940.
[3] At refineries only.

Photo shows the Super-Diamond Pattern of "A.W." Rolled Steel Floor Plate. Provides completely safe tread from any angle, under any condition.

Floor troubles ended for good . . . Wherever floors do double duty—traffic aisles, stair treads, railroad running boards and platforms, car steps, truck body floors, engine rooms, catwalks, refinery towers—"A.W." Rolled Steel Floor Plate helps to prevent dangerous and costly slips and falls. Reduces maintenance to a minimum. With "A.W." Floor Plate, there are no worn and slippery surfaces to endanger men on foot or upset floor trucks. Write for folder giving complete engineering data.

ALAN WOOD STEEL COMPANY

MAIN OFFICE AND MILLS, CONSHOHOCKEN, PENNA. : : SINCE 1826 : : DISTRICT OFFICES AND REPRESENTATIVES—Philadelphia, New York, Boston, Atlanta, Buffalo, Chicago, Cincinnati, Cleveland, Denver, Detroit, Houston, New Orleans, St. Paul, Pittsburgh, Roanoke, Sanford, N.C., St. Louis, Los Angeles, San Francisco, Seattle, Montreal—A. C. Leslie & Co. PRODUCTS INCLUDE—Steel Products in Carbon, Copper or Alloy Analyses : : Sheared Steel Plates : : Hot Rolled Sheets and Strip : : "A.W." Rolled Steel Floor Plates : : Billets, Blooms and Slabs : : "Swede" Pig Iron : : Reading Cut Nails.

surplus of at least 15,000,000 barrels, being that much greater than the over-large inventory of a year ago, while total demand is up only a small percentage, with exports down sharply.

While the weakness of gasoline has been the most serious difficulty in the industry's markets, there has been a protracted decline in prices of lubricants, which finally has caused a 25-cent reduction in the postings for Pennsylvania grade crude.

The past few weeks have brought, moreover, reductions in wholesale prices of kerosene, light fuel oils, and heavy fuel oils, although the lowering of the heating oil quotations may have been primarily of seasonal nature.

Demand Situation

Total demand for United States petroleum has set new records this year, despite curtailed exports, as domestic consumption has exceeded all previous peaks, with all products in wide use. However, as the year has progressed, the margin of increase over 1939 curves has narrowed. In March, latest month for which official figures are available, the gains over 1939 were smaller than those for the opening months of the year.

In the first three months of 1940, total demand for United States petroleum was 6.6 percent greater than that in the corresponding months of 1939, on a daily average basis. Domestic demand was up 10.8 percent, but total exports were down 22.7 percent, as shipments of crude oil were down 18.8 percent and those of refined products 24.8 percent.

All corresponding figures for March were lower, total demand having been 4.4 percent larger than in March, 1939, as a 9.3 percent gain in domestic consumption was offset to a large extent by a 36.5 percent decrease in total exports, with crude shipments down 18.5 percent and refined oil exports off 30.1 percent.

Virtually all refined products show, for both the first three months and March, increases in domestic demand and decreases in exports, when 1940 figures are compared with 1939 data. The only products that have been exported in increased quantities following outbreak of the European war have been aviation gasoline, lubricants, and wax.

In the first seven months of the war, exports of United States crude and refined oils totaled 92,279,000 barrels, about 10,000,000 barrels, or 10 percent, less than the 102,343,000 barrels shipped out in the corresponding seven months a year earlier. Crude oil shipments were down 4.5 percent for the period, while refined products in the aggregate showed a decrease of 12.9 percent. The most important loss of business has been that in shipments of ordinary gasoline, which were 8,000,000 barrels, or 28 percent, smaller in the first seven months of the war than in the comparable months a year before. Exports of heavy fuel oils meanwhile were down about 2,500,000 barrels, or 23 percent. Shipments of kerosene and light fuel oils also have contracted. Details of the trends in exports of the various products since the beginning of the war appear in an accompanying table.

Similarly, recent trends in domestic consumption of the different products are shown in another table.

In view of the prevailing demands for the various refined products, present inventories of those oils are generally satisfactory, with exception of the previously mentioned surplus stocks of gasoline and the inadequate supplies of heating oils. In one of the tables presented herewith, inventories of the various products are compared with those held a year ago.

Following the effectiveness of the Venezuelan trade agreement at the middle of December, domestic oil producers have had to make room in their markets for materially increased imports of foreign crude and fuel oils. As shown in a table, imports aggregated 14,364,000 barrels in the first three months of 1940, compared with only 5,838,000 barrels in the corresponding months of 1939. Imports of crude oil were up to 6,902,000 barrels from 4,043,000, and those of refined products, mostly fuel oil, were up to 14,364,000 barrels from 5,838,000. The imports of both crude and refined oils were especially heavy in March.

Oil Imports for Domestic Use Up Sharply

Figures indicate barrels and are from Bureau of Mines.

MONTH	Crude Oil	Refined Products	Total
January:			
Jan., 1939....	1,373,000	609,000	1,982,000
Jan., 1940....	1,664,000	1,321,000	2,985,000
Percent Change.	+21.2	+117.1	+52.0
February:			
Feb., 1939....	1,266,000	654,000	1,920.000
Feb., 1940....	2,343,000	2,731,000	5,074,000
Percent Change.	+85.0	+320.0	+164.0
March:			
Mar., 1939...	1,404,000	659,000	2,063,000
Mar., 1940...	2,895,000	3,410,000	6,305,000
Percent Change.	+106.2	+417.4	+205.6
1st 3 Months:			
1939.....	4,043,000	1,795,000	5,838,000
1940.....	6,902,000	7,462,000	14,364,000
Percent Change.	+70.7	+315.6	+146.0

Oil Exports Down Sharply in First Seven Months of War

(Figures indicate barrels, except as otherwise noted)

	SEVEN MONTHS PERIOD			MONTH OF MARCH		
	Ending March 31, 1939	Ending March 31, 1940	Percent Change	1939	1940	Percent Change
Item:						
Crude oil	37,095,000	35,430,000	— 4.5	4,966,000	4,046,000	— 18.5
Products:						
Motor fuel	28,058,000	19,813,000	— 28.4	4,336,000	[5]2,265,000	— 47.7
Aviation gasoline	[1]1,127,000	[2]1,462,000	+ 29.7	392,000	249,000	— 36.5
Kerosene	4,516,000	3,877,000	— 14.2	546,000	485,000	— 11.2
Gas oil and distillate	15,415,000	14,986,000	— 2.8	2,924,000	2,318,000	— 20.7
Residual fuel oil	10,681,000	8,196,000	— 23.3	2,047,000	932,000	— 54.5
Lubricants	5,302,000	7,847,000	+ 48.0	829,000	1,193,000	+ 43.9
Wax (thousands of pounds)	148,809	151,429	+ 1.8	26,384	25,642	— 2.8
Coke (short tons)	103,000	147,700	+ 42.7	9,800	13,700	+ 39.8
Asphalt (short tons)	31,600	374,800	+1086.0	2,700	[3]18,900	.....
Miscellaneous	61,000	440,000	+ 621.3	9,000	126,000	+1300.0
[4]Total Refined Products	65,248,000	56,849,000	— 12.9	10,849,000	[6]7,583,000	— 30.1
Total Crude and Products	102,343,000	92,279,000	— 9.8	15,815,000	11,629,000	— 26.5

[1] September, October, November, 1938, not included. [2] September, 1939, not included. [3] Beginning January, 1940, includes both manufactured and unmanufactured asphalt; only unmanufactured asphalt being previously shown. [4] Not the sum of above figures, some of which do not indicate barrels. [5] Includes benzol, 9,000 barrels in March, 1940. [6] Exclusive of 13,000 barrels exported from non-contiguous territories, but inclusive of 748,000 barrels shipped from U. S. to territories.

Above figures from Bureau of Foreign and Domestic Commerce.

No Action Expected On Cole Bill

Failing a demand by the Administration for additional authority, no action is expected this session on the Cole bill to vest the Secretary of the Interior with authority over the production of oil.

It was explained by the committee that the final volume of the hearings held some time ago has not yet been printed, and that the committee will not consider the bill until all the testimony is available.

At the same time, it was indicated, no effort is being made to speed up the printing, which includes an index of witnesses and subjects, and that there was little disposition on the part of the committee to attempt to push the measure this year.

In the event the president asks for authority over industry to insure a constant and adequate flow of needed commodities, the bill may be revived; but in view of the fact that the oil industry today is operating at a very low percentage of possible production, it is not believed it will be the subject of such a move.

Petroleum Tax Raise Proposed

Increases in existing federal taxes on petroleum products were listed in the legislation under consideration by the House Ways and Means Committee as part of the measure to defray defense costs. The bill would increase the tax on lubricating oil 10 percent while the tax on gasoline would be increased ½ cent per gallon. Additional revenues contemplated are $1,500,000 from lubricating oil and $112,000,000 from gasoline.

The legislation is calculated to add revenue of $656,000,000 each year for 5 years.

In addition to the direct taxes on oil and other commodities, the bill provides for a 10 percent increase in personal and corporation incomes and a 20 percent increase in the transfer tax on stocks and bonds.

Labor Complaint Dismissed

Dismissal of a complaint alleging that Crown Central Petroleum Corporation had engaged in unfair labor practices at its Pasadena, Texas, plant, was announced June 3 by the National Labor Relations Board, which at the same time directed a secret ballot election, to be held within 30 days, to determine whether the company's employes wish to be represented for collective bargaining purposes by the Oil Workers International Union (CIO), the Employes Federation of Pasadena, or by either.

The complaint was filed June 28, 1939, charging that the company had interfered with the self-organizational rights of its employes.

Another charge, that the company had dominated or interfered with the formation and administration of the Employes' Federation, was held not to have been proven, nor that it had been hostile to the CIO union.

The Look Box

Oil Taxes at High Levels

Treasury collections from the federal taxes on the oil industry continued heavy in April, but revenue from levies on lubricating oils and transportation by pipe line failed to maintain their March levels.

Gasoline tax collections increased to $15,184,770 from $14,909,664 in March and were practically unchanged from April, 1939, when $15,182,328 was received, the bureau reported.

Receipts from lubricating oils declined for the third successive month, dropping from $2,074,041 in March to $2,026,048 in April, where they were some $164,000 under the $2,190,594 collected in the same month last year.

Pipe line transportation paid taxes of $806,633, more than $225,000 under the $1,032,149 reported for March, but $72,000 above the $734,658 collected in April, 1939.

For the first four months of the year, however, collections from all three taxes were ahead of 1939, the gasoline tax returning $67,715,332 against $62,617,157, lubricating oil $9,351,988 against $8,688,679, and pipe line transportation $3,897,700 against $3,588,820.

The three levies combined will return to the Treasury considerably more for the fiscal year which ends June 30 than was received in the 1939 year, the bureau stated. For the first ten months of the fiscal year, the gasoline tax returned $186,142,430, a gain of $13,296,754 over the $172,845,676 reported to the end of April, 1939; lubricating oils returned $25,454,751, a gain of $3,118 over $25,451,633, and pipe line transportation returned $9,440,297, a gain of $326,325 over $9,113,972.

CONVENTIONS

JUNE	
17–20	**American Society of Mechanical Engineers, Milwaukee.**
20–21	**Pennsylvania Grade Crude Oil Association, Hotel Emery, Bradford, Pennsylvania.**
25–28	**American Society for Testing Materials, Chalfonte Haddon Hall, Atlantic City.**
SEPT.	
9–13	**American Chemical Society, Detroit, Michigan.**
18–20	**National Petroleum Association, Hotel Traymore, Atlantic City.**
30	**National Lubricating Grease Institute, Stevens Hotel, Chicago.**
7–10	**American Gas Association, Atlantic City.**
NOV.	
11–15	**American Petroleum Institute, Stevens Hotel, Chicago.**

N.G.A.A. Officials Reelected

Officials of the Natural Gasoline Association of America were reelected at the nineteenth annual convention in Tulsa May 15-17. They are George P. Bunn, Phillips Petroleum Company, Bartlesville, president; J. R. Jarvis, Lone Star Gasoline Company, Dallas, Ray E. Miller, Hanlon-Buchanan, Inc., Tulsa, and J. W. Vaiden, Skelly Oil Company, Tulsa, vice presidents.

Directors chosen for two years will be named from personnel of the following company members: Phillips Petroleum Company, Bartlesville; Hanlon-Buchanan, Inc., Tulsa; Skelly Oil Company, Tulsa; Standard Oil Company of California, San Francisco; Kansas Power & Light Company, Salina; Indian Territory Illuminating Oil Company, Bartlesville; Coltexo Corporation, Monroe, Louisiana; United Gas Pipe Line Company, Shreveport; Warren Petroleum Company, Tulsa; Glacier Production Company, Cut Bank, Montana; Glen Rose Gasoline Company, Tulsa; Lisbon Gasoline Company, Shreveport; Hercules Gasoline Company, Shreveport; The Carter Oil Company, Tulsa, and Sabine Valley Gasoline Company, Shreveport.

Directors who hold over for another year are from these member companies: Lone Star Gasoline Company, Dallas; Parade Gasoline Company, Shreveport; Continental Oil Company, Ponca City; Carbide and Carbon Chemicals Corporation, New York; Shell Oil Company, Tulsa; Union Oil Company, Los Angeles; Texas Pacific Coal & Oil Company, Fort Worth; Oklahoma Gasoline Plants, Inc., Sapulpa; Owens-Libbey-Owens, Gas Department, Charleston, West Virginia, and Cities Service Oil Company, Bartlesville.

Brown Gets Hanlon Award

The Hanlon award, given each year by E. I. Hanlon, Tulsa banker and industrialist, went to Dr. George Granger Brown, professor of chemical engineering at the University of Michigan, who over a period directed research activity of the association. His paper on the recent program at Tulsa dealt with gas measurement, under the title, "Natural Gas Under Pressure." He gave it orally since one part has not been completed for printing.

In making the donation, a gold watch, George P. Bunn said of Dr. Brown:

"Because of considerable outstanding research at Michigan he was sought by our association as a consultant to assist in the solution of the problem of what to do with natural gasoline. Although working under the auspices of the association, he has given the entire natural gasoline industry invaluable service. On his first appearance among us he made the startling statement that up to 50 percent of natural gasoline could be blended with then currently available motor fuel with excellent results. He subsequently instituted comprehensive research into engine performance to further prove his statements and to simplify his findings concerning the value of our product. Lectures and demonstrations before numerous scientific and industrial groups did much to further the interests of the industry. He has made no small contribution to the

gradual increase in motor fuel volatility. Although his final report on the initial investigations was presented in 1930, he has continued to serve us in other directions and is still showing up each year to give us something new to think about. His greatest accomplishment in the eyes of this industry has been, perhaps, to sell the virtues of natural gasoline to the natural gasoline manufacturers themselves. And now, after all his work, it looks like we are right back where we started. He may have to begin all over again to find out what to do with natural gasoline."

"Kinks" Contest

In the "kinks" contest, the grand prize went to D. B. Young, whose arrangement of a liquid level controller in the Class B section of the contest also drew the award, $25, as a grand award. He is with the J. E. Crosbie, Inc., in its Fittstown gasoline plant.

The first award in Class A was won by Hugh T. Greiner, Seminole plant of Gulf Oil Corporation, for his easy packing puller. Second prize went to J. R. Green, Skelly Oil Company, Carter 9 plant, for an automatic shutdown device. W. A. Ryan, J. E. Crosbie, Inc., Fittstown, won third place with a bearing cone-puller. Fourth prize was won by W. H. Williams, Warren Petroleum Corporation, Graham plant, for an ignition system.

Class B awards were: Roy Magerkurth, Phillips Petroleum Company, Oklahoma City plant, hydraulic pump for hydrostatic testing; Richard W. Weeks, Phillips Petroleum Company, Phillips, Texas, plant, a device to empty, check and refill sealing liquid pots; Richard W. Weeks, for dials to indicate orifice size within a Daniels orifice fitting, and John L. Boyd and E. A. Thoes, Orlando plant, Shell Oil Company, for tank pressuring with the gas.

There were no entries for Class C devices. In Class D, J. M. Hester, Shidler plant, Skelly Oil Company, was first with a gate tester. Harvey Miller, Phillips Petroleum Company, Oklahoma City, for a condenser tube tester, was second. Third place went to H. E. Chambers, Lyman plant, Skelly Oil Company, for a pump arrangement to take gas samples from vacuum lines. Roy Magerkurth, Oklahoma City plant of Phillips Petroleum Company, took fourth place with a fitting thread leak clamp.

All entertainment, two luncheons and the dinner dance, were provided by the Natural Gasoline Supply Men's Association, which held its annual meeting May 15 and elected the following officials: W. W. Woobank, Woobank Pump & Machinery Corporation, president; L. S. Allen, National Tank Company; R. T. Roberts, Goulds Pumps, Inc., and D. A. Leach, Chicago Bridge & Iron Company, vice presidents; William F. Lowe, secretary.

R. T. Roberts and D. A. Leach were elected to the board of directors, which included the following: C. D. Peterson, Fisher Governor Company; Egon Keehler, Moorelane Company; W. M. Gebo, Ingersoll-Rand Company; V. C. Canter, Frick-Reid Supply Corporation, and George P. Bunn, president of the Natural Gasoline Association of America.

1 SEAMLESS
2 UNIFORMLY FULL PIPE THICKNESS
3 SELECTIVE, UNIFORM REINFORCEMENT
4 TANGENTS
5 MACHINE TOOL BEVELLED
6 END MARKED IN QUARTERS
7 COMPLETE IDENTIFYING MARKS ON EVERY FITTING
8 A FULL LINE
Of course
— the fittings with the MOST advantage are the fittings that can be used to BEST advantage. Weld-ELLS have these eight features that are combined in no other welding fittings.
TAYLOR FORGE & PIPE WORKS
General Offices and Works:
P. O. Box 485, Chicago
New York Office: 50 Church St.
TAYLOR FORGE
WeldELLS

A.S.T.M. Annual Meeting

A report of Committee D-2 on petroleum products and lubricants will be a part of the program of the annual meeting of the American Society for Testing Materials, Atlantic City, June 24-28. Advance information on this report is that procedure for calculating viscosity index will be presented as well as new methods of test for dropping point of lubricatng greases. A new method proposed for testing for the aniline point of petroleum products and a revision of the Diesel fuel oil classification, and a test for the ignition quality of Diesel fuels are to be offered for information. Other subjects have been thus listed:

"A report also recommends for immediate adoption revisions in six standard methods which cover two distillation tests of gasoline, Pensky-Martens flash point test, knock characteristics of motor fuels, water test and methods of analysis of grease. The specifications for Stoddard solvent and the test for sulfonated residue of plant spray oils are recommended for adoption as standard. Revisions are submitted in four tentative methods. A revised procedure for neutralization number is also presented as tentative."

T. A. Boyd, General Motors Research Corporation, is chairman of the committee and chairman of committee Z-11, which is to have a report on petroleum products and lubricants.

Most of the other work within the division on petroleum products will deal with asphalts and road materials.

Brown Elected S. O. I. Director

Bruce K. Brown, manager of research and development for Standard Oil Company (Indiana), has been elected a member of its board of directors. He has been with the concern since 1929, when he became patent attorney. He served as manager of the development and patent department before taking over present duties, which include supervision of research activities in six refining plants as well as patent and technical developments.

A.P.I. Pledges Defense Aid

Cooperation of the petroleum industry in any military defense plan of the federal government was pledged through resolution of directors of the American Petroleum Institute at the mid-year meeting in Fort Worth, May 29. Another resolution was passed approving the principles of legislation for a proposed special militia to be known as the national industrial defense corps.

Concerning the attitude of the industry toward defense the resolution said:

"The American petroleum industry pledges its full, complete and voluntary cooperation with the government of the United States and with all agencies of the government in the furtherance of national defense and security.

"The resources, the facilities, the services and the personnel of the industry can be voluntarily and effectively mobilized in a cooperative program of government and industry for national defense, and the industry pledges with

Another... LUMMUS CRACKING UNIT *Accepted*

This one after 18 days of initial run

For a major oil company Lummus recently completed a Lummus Combination Three-Coil Cracking Unit . . . viscosity-breaking, gas oil and heavy naphtha reforming. » » » Eighteen days after the unit was put on stream it was completely accepted, having met all guarantees. The initial run was continued to 25 days, when the unit was shut down for inspection purposes. » » » This recently completed unit — the ninth consecutive Lummus Cracking Unit to be accepted during initial firing runs of 25 days or more — is equipped with Lummus Floor-Fired, Raised Hearth Heaters, with improved steam generation feature in the convection section. Provision is also made for steam generation from waste heat.

THE LUMMUS COMPANY, 420 Lexington Avenue, NEW YORK, N. Y.

600 SOUTH MICHIGAN AVENUE, CHICAGO, ILL. • 411 WEST FIFTH STREET, LOS ANGELES, CAL. • 3028 WROXTON AVENUE, HOUSTON, TEXAS
BUSH HOUSE, ALDWYCH, LONDON, W. C. 2

LUMMUS

PETROLEUM REFINING PLANTS

Rush work on Claytower Screens . . . without sacrifice of quality . . . is our forte.

Modern Arc- and Spot-Welding technique makes "Multileaves" better.

JUST THREE OUT OF MANY

Refinery operators in constantly increasing numbers are learning the benefits to be derived from turning their wire and filter cloth problems over to Multi-Metal for solution. It is rare indeed that we cannot suggest new materials or methods which increase efficiency or assure a better product—or both.

In a comparatively brief period we reduced by 80% the cost of his Graytower Screens for one client.

For another client we installed a set of "Multileaves" in a contact plant press which handled in thirty minutes the same amount of oil it had formerly taken ninety minutes to handle.

The use of a different filter cloth and the installation of spacing screens in another refinery reduces the pressure necessary to force the vapors through the cloth from 60 lb. to 8 to 10 lb.

Savings like these are by no means uncommon when a refiner consults us regarding his wire and filter cloth problems. Why not see what we can do for you? . . . Write, wire or phone us now.

MULTI-METAL
WIRE CLOTH COMPANY
INCORPORATED
1356 GARRISON AVE., BRONX BORO, N. Y.

WIRE CLOTH
FILTER CLOTH
ALL MESHES
ALL METALS

confident assurance the ability to furnish a complete, adequate and continuous supply at all times, wherever desired, of petroleum and its products to the fullest requirements of the military and naval establishments of the United States, as well as the industrial and civilian requirements of the nation."

Another board resolution ended the program of public relations, which was expanded following the annual meeting in 1939. This resolution was that, "in view of changed conditions in the country, and in the industry it now appears undesirable for the institute to engage in a general campaign such as was contemplated when the original action was taken." The resolution provided that the department of public relations continue to function as it did prior to creation of the larger committee organization, which was discontinued.

One session of the Refining Division at the mid-year meeting of the American Petroleum Institute, Fort Worth, May 27 to May 30, was devoted to refinery corrosion. Four of the six papers from this symposium are abstracted below. The other two are given in full in this issue along with most of the other papers out of the three sessions of the Refining Division.

Also in abstract form are two papers out of the fuels session, one of which is used in full in this issue.

Corrosion of Copper and Copper-Base Tubing in Oil Refinery Heat Transfer Equipment

By J. A. Wilkins, E. S. Bunn *and* W. Lynes
Revere Copper and Brass, Inc., Rome, New York.

The authors divided the subject into corrosion on the oil side and corrosion on the water side of equipment. Below 500° F. on the oil side they said little damage would come from oil associated sulfur compounds, however, "severe corrosion may occur when the oil carries ground water, acidic from hydrolysis or chlorides or the presence of hydrogen sulfide or alkaline from excessive ammonia treatment."

At temperatures higher than 500° F. their conclusion was that corrosion occurs chiefly from hydrogen sulfide, with pressure and velocity of the oil or vapor playing a part in action on equipment.

Destruction of equipment on the water side was divided as follows: corrosion—metal solution; corrosion stress—static stress and cyclic stress; corrosion impingement—impingement of liquids and impingement of gases; corrosion stress impingement—cavitation.

Control of corrosion was considered from two angles—selection of the proper metal and treatment of both oil and water to counteract action on metal.

The authors listed 104 references in technical literature for further study of the subject.

Copper Alloys and Their Application in Petroleum Refining

By James T. Kemp
The American Brass Company, Waterbury, Connecticut.

Refiners use the copper alloys for tubes and tube sheets in heat exchangers; for baffle and turbulence plates; for pipe for conveying dilute acid and the residues from acid treatments; for water supply systems; for strong corrosion-resistant bolts, screws and fastenings; for parts of machinery;

WHO uses the GIRBOTOL PROCESS for GAS PURIFICATION? . . .

THE Girbotol Process is the easiest, cheapest, most effective process ever developed for gas purification (and dehydration). Capacities of individual existing plants now run all the way from 100,000 cubic feet to 50,000,000 cubic feet per day. . . . If you have *any* sort of purification or recovery problem, we would welcome an opportunity to consult with you. *Address:*

Gas Processes Division, THE GIRDLER CORPORATION, Incorporated, LOUISVILLE, KENTUCKY

A PARTIAL LIST OF GIRBOTOL PROCESS USERS

ATLANTIC REFINING CO.
CABOT CARBON CO.
CALIFORNIA CARBONIC CO.
CARBO CHEMICAL CO.
CHARTIERS OIL CO.
CITIES SERVICE GAS CO.
CITIES SERVICE OIL CO.
COLUMBIAN CARBON CO.
GODFREY L. CABOT, INC.
GULF OIL CORPORATION
IMPERIAL CHEMICAL INDUSTRIES, LTD.
LA FABRICA DE CERVEZA DE SAN MIGUEL
LAGO PETROLEUM CORPORATION
LIQUID CARBONIC CORPORATION
LOUISVILLE GAS AND ELECTRIC CO.
MONSANTO CHEMICALS, LIMITED
NORTHERN NATURAL GAS CO.
N. V. DE BATAAFSCHE PETROLEUM MAATSCHAPPIF
PHILLIPS PETROLEUM CO.
PROCTER AND GAMBLE CO.
PRODUCERS GAS CO.
SOCIETE ANONYME DES PETROLES JUPITER
SOCONY-VACUUM OIL COMPANY
SOUTH PENN OIL COMPANY
STANDARD OIL COMPANY OF CALIFORNIA
STANDARD OIL COMPANY OF INDIANA
STANDARD OIL COMPANY OF LOUISIANA
STANDARD OIL COMPANY OF NEW JERSEY
SUN OIL CO.
TIDE WATER ASSOCIATED OIL CO.
TRI-ESS CORPORATION
UNITED FUEL GAS CO.

TYPICAL GIRBOTOL APPLICATIONS

Purification of natural gas for—
- *industrial and domestic consumption*
- *preventing diffusion of sour gas into sweet gas sands*
- *repressuring sweet oil fields*
- *manufacture of carbon black*
- *production of blending agents for high-test motor fuels*
- *gas engine fuel*
- *camp cooking and heating*
- *water well lift pumping*

Purification and dehydration of natural gas to prevent corrosion and hydrate formation in transmission lines and equipment.

Purification of refinery and casinghead gas for—
- *feed stock to polymerization and alkylation plants*
- *recovery of sweet propane and butane fractions*
- *reduction of corrosion in lines and processing equipment*
- *synthesis of iso-octane*
- *synthesis of hydrogen*
- *synthesis of industrial chemicals*

Purification of gas from sewage disposal plants.

Recovery of H_2S for sulphuric acid and chemical manufacture.

Removal of CO_2 from raw hydrogen.

Production of inert atmospheres from combustion gases.

Recovery of CO_2 for—
- *production of liquid CO_2*
- *production of dry ice*
- *use in mining of bituminous coal*
- *manufacture of salicylic acid and aspirin*

Spring Regulators on the Lines of a Big Gas Company

Easy to deliver, easy to install, self-protective against meddling, C-F spring-loaded Regulators are preferred in some conditions of service to those of weight-and-lever type. A high-pressure and a low-pressure unit on lines of an important gas company in Texas are here illustrated. C-F meets all requirements of pressure control. Write for new Catalog.

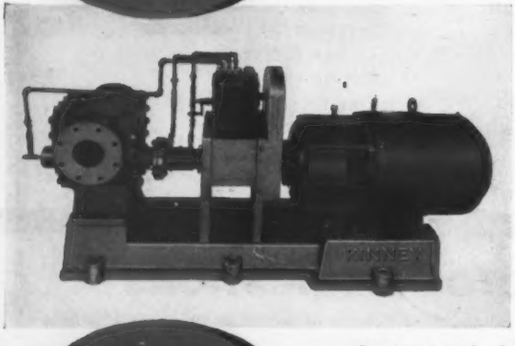
The CHAPLIN-FULTON MFG. CO.

28-40 PENN AVE. CF PITTSBURGH, PA.

KINNEY PUMPS

ACID SLUDGE successfully handled with Kinney "SD" Pump

Handling acid sludge from the treatment of raw cracked naphtha is a real pumping job. The Kinney SD is adapted to this severe service by use of a special stuffing box to prevent any leakage, and a self-contained lubrication system.



Pumps already in service are handling up to 50 g.p.m. with suction pressures up to 75 lbs. and a differential pressure of 50 lbs. The sludge has been handled at low temperatures and at a viscosity of about 150,000 s.s.u.

Illustration shows the complete pumping unit: pump at left, lubricator mounted above coupling, and motor drive. Lubricator is driven by V-belt connection to pulley on motor shaft and furnishes oil to the pump bearings, and, through the shaft, to surfaces between the cams and pistons; a separate line maintains a pressure oil seal on the pump stuffing box.

If interested in this or any Kinney Pump, address the nearest office:

Kinney MANUFACTURING COMPANY
3539 Washington Street
Boston, Mass.

New York
30 Church St.

Dallas
808 Santa Fe Bldg.

Philadelphia
725 Commercial Trust Bldg.

Los Angeles
1333 Santa Fe Ave.

Chicago
1202 Buckingham Bldg.

San Francisco
King-Knight Co.

electrical equipment and many other purposes, including protective linings.

The metal manufacturer is very cooperative in advising and supplying material to refiners who do research work of their own and in opening his laboratories for inspections that cannot be made conveniently elsewhere. The results of the work on elevated temperature testing, on creep, and on exposure to steam, natural waters, the atmosphere, etc., which work is now under way, will be available in due course and will be applied directly or indirectly to the advantage of refineries as well as to other industrial users of non-ferrous metals.

Results of Corrosion Tests in Oil Refineries

By N. W. Mitchell
Chase Brass and Copper Company, Waterbury, Connecticut.

The report is not complete, since the experiments are being continued. The experiments are being determined on tensile strength loss rather than weight loss, which the author explained as:

"There are several reasons, it is felt, why tensile strength losses are much more satisfactory for estimating corrosion resistance of copper alloys than measurements of weight loss. Many of the copper alloys suffer selective solution—a form of corrosion in which often the metal is much damaged and sometimes rendered worthless for service, without appreciable loss in weight."

Two tabulations, one giving results when the attack on metal was predominantly from sulfur and the other when the attack came from water, are offered. The experiments are being continued. Results are thus summed up:

"The results obtained from the test racks of specimens correspond very closely to those results which have been obtained in laboratory corrosion tests and also are in close accord with the behavior of the same metals in service in tube form."

Testing of Brass Alloys for Dezincification Resistance

By F. M. Barry
Scovill Manufacturing Company, Waterbury, Connecticut.

A 1 percent solution of cupric chloride was selected for conducting studies in dezincification. One series of tests was conducted at 80° F., the other at 120° F. The testing was further described:

"A large number of specimens was started at the same time, both at room and elevated temperatures, each specimen being immersed in an individual glass jar. After definite intervals certain specimens were withdrawn, whereas others were continued for longer test periods. In this way a record was made of the progress of the test over the total testing period. In all cases the test specimens were finish-annealed; no special preparation of their surfaces was followed except for a final acid cleaning similar to that employed in commercial practice."

His conclusions were:

"The tests indicate that the addition of phosphorus, antimony or arsenic to admiralty metal in amounts up to approximately 0.05 or 0.06 percent will inhibit dezincification under the particular conditions of the test.

"Intercrystalline corrosion of arsenical admiralty metal has been revealed by the cupric chloride test, particularly at elevated temperatures (120° F.).

"The cupric chloride test is useful only

TERRY

Multi-Stage and Single-Stage Steam Turbines for All Mechanical Drive Applications

Terry Turbines are built in all sizes up to 2000 HP and for all commercial steam pressures and exhaust pressures. They are available for condensing, non-condensing, low pressure, mixed pressure and bleeder operation.

The types include

—Terry Solid Wheel Turbines.
—Single Stage Axial Flow Turbines, using either two or three rows of blading.
—Multi-Stage Impulse Turbines.

Our engineers will be glad to submit data and estimates on the proper type to meet your requirements.

THE TERRY STEAM TURBINE COMPANY
TERRY SQUARE, HARTFORD, CONN.

in determining the dezincification resistance of brasses. The results of this test cannot be used to predict the behavior in service of such alloys when subjected to other forms of corrosion."

Performance Testing of Motor Fuels

By Herschel G. Smith
Gulf Oil Corporation,
Philadelphia, Pennsylvania.

This is a progress report on the third year of operation with the AIL (acceleration-inertia-load test). It described an improved design of duplex unit employing two engines, with combination or single fly wheel and water brake. The abstract by the author was:

"A number of formulas that have been developed for the calculation of the approximate octane performance values by the AIL method are disclosed as an indication of probable average road performance; also for conversion from one standard method to another, merely with the use of factors involving the usual inspection data and the octane number value by any one method. These conversion formulas usually yield values that are within the limit of error of the respective determinations as carried out by different laboratories. Although perhaps not quite accurate in all cases as the actual determinations of the results by any one laboratory, the derived values appear to be sufficiently accurate for most operating or design purposes; so that considerable savings appear possible in laboratory work in the way of simplification of motor testing activities of all kinds."

STREAMLINED walls AND arches
FOR OIL HEATERS

A new low cost has been achieved by eliminating bulk and weight in heater walls and arches. The new THINSULITE Construction is thinner, lighter and thoroughly insulated, yet it retains the flexibility that goes with Detrick Suspended Construction, providing a permanently heat and air-tight wall.

Another saving in cost is the omission of the outside casing and the substitution of a hard weather-proof finish which is applied in plastic form.

DETRICK THINSULITE
thin-insulated-light

THINSULITE is a new type of construction
It is built with first grade refractory 3 or 4½ inches thick, backed up with insulation and supported by light steel members. It has the advantage of a completely suspended construction combined with the economy of a thin wall.

DETRICK INSULATION
Made by DETRICK
For every Heat Insulation requirement Detrick offers many distinct advantages.
BLOCK
BLANKET
PLASTIC
CONSULT US ON INSULATION PROBLEMS
Pioneers of Furnace Engineering and Insulation

Suitable for boiler walls, water wall backing, oil still heaters, stress relieving furnaces. In fact, THINSULITE Construction is practical for all areas not exposed to actual abrasion.

See the heat transfer curves and application details in the new THINSULITE Catalog, available on request.

M. H. DETRICK COMPANY
Since 1913
140 South Dearborn St.
CHICAGO, ILLINOIS

Petroleum on A.C.S. Program

The Petroleum Section of the American Chemical Society is arranging a symposium on "Petroleum Chemistry's Contribution to the Automotive Field" as its part on the program of the annual meeting in Detroit the second week in September. The program is being prepared by this committee: M. R. Fenske, chairman; T. A. Boyd, G. M. Maverick, E. C. Williams.

Papers are to fall within the following five classes:

Petroleum as a source of automotive power, automobiles, airplanes, trucks and tractors.

Petroleum as a lubricant, from the standpoint of physical properties, manufacturing operations and performance.

Petroleum as a special material for use in coatings, lacquers and finishes, plastics and such special products as are used in hydraulic drives and shock absorbers.

Petroleum on the road, asphalts, road oils and emulsifiers.

General papers discussing such subjects as chemical construction of petroleum, new reactions in petroleum chemistry and advances in refining equipment.

War Threatens Lower Consumption

Placing the market demand for crude oil in June at 3,620,300 barrels a day, 19,300 barrels more than the estimated demand for May but 21,000 barrels below actual demand in June, 1939, the United States Bureau of Mines on May 20 warned the industry that war conditions threaten further contraction of exports, which will offset much of the anticipated increase in domestic consumption.

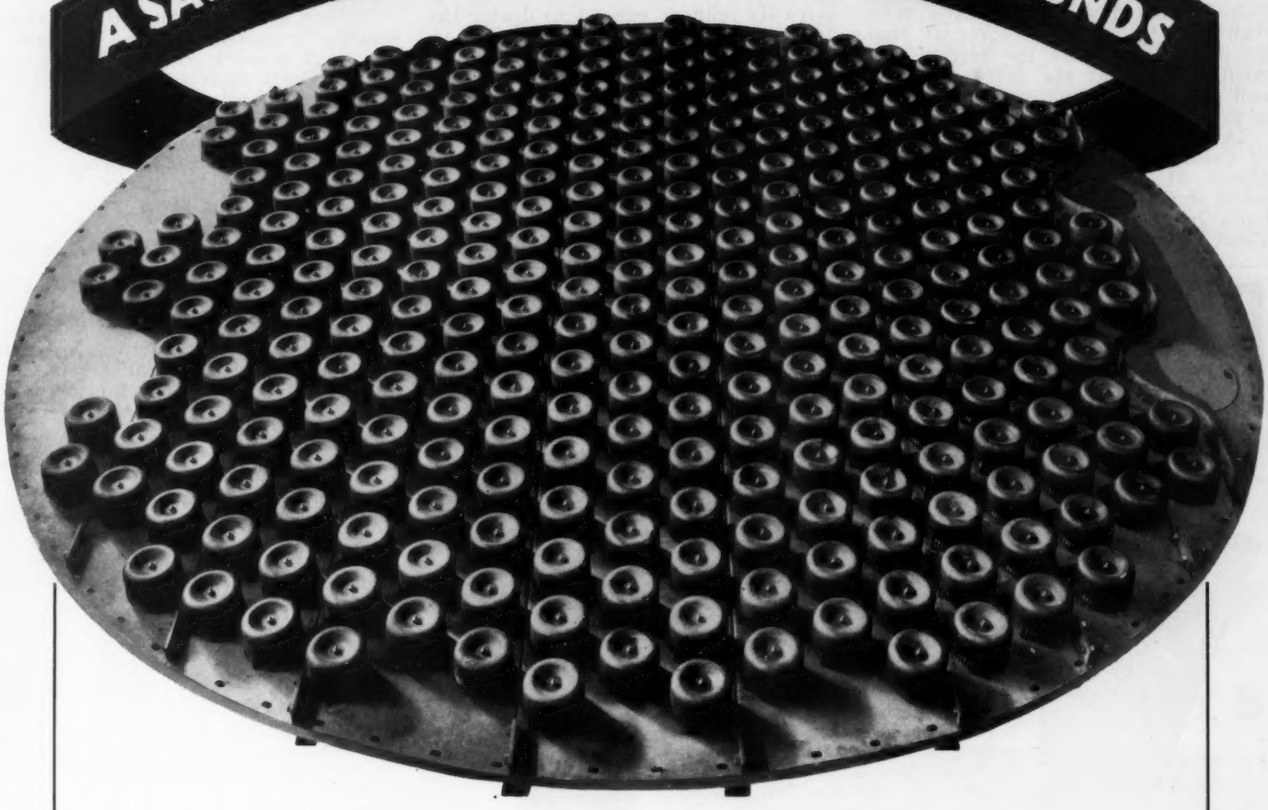
The figure set by the bureau for June is 253,100 barrels a day less than actual output in March, the last month for which government figures are available.

The bureau pointed out that daily average crude production during the four weeks from April 7 to May 4 was 3,809,000 barrels and runs to stills 3,541,000 barrels, while domestic crude stocks increased at the rate of 227,000 barrels a day, indicating a demand of 3,582,000 barrels daily, compared with 3,550,000 barrels estimated by the bureau. It was explained, however, that runs to stills were 150,000 barrels a day more than the bureau estimated, resulting in an increase of about 800,000 barrels in gasoline stocks instead of the substantial decrease which had been estimated.

"Current war conditions indicate further interruptions to our export trade in oil," the bureau warned, "consequently reduced estimates of exports offset much of the anticipated increase in domestic demand.

"An adequate seasonal reduction in the abnormally high stocks of gasoline will mean that currently less gasoline production is required than last year, although the increased demand for all products may require that substantially the same amount of crude be run to stills. Increased demand for fuel oils, coupled with depleted stocks east of California, indicate the continuance of lower gasoline yields and higher distillate fuel-oil yields if a better balance

A SAVING IN WEIGHT OF OVER 3500 POUNDS



ABOVE is a photograph of an assembled Light-weight Alloy Tray complete. Total weight, including Bubble Caps, Risers and all Bolts and Nuts, 1780 pounds, a saving in weight over the cast iron type of over 3500 pounds. The assembly shown here is 13 feet, 7½ inches in diameter, with a tray section of 14 gage material and the Caps and Risers of 16 gage material. The entire job as shown was made by The Pressed Steel Company.

Over 60% of the oil industry are now using our Bubble Caps in Fractionating Equipment. We can furnish a style of Bubble Cap that will fit your present construction.

★

The Pressed Steel Company

WILKES-BARRE • PENNSYLVANIA

between products is to be established."

Domestic demand for motor fuel during the coming month is estimated by the bureau at 53,200,000 barrels, a gain of 7 percent over the June, 1939, demand.

An estimate of 2,400,000 barrels for export is 400,000 barrels less than the estimate for May, and but little more than half the actual exports of June last year. Indications, the bureau commented, are that the allied countries will continue to supply the major part of their needs from other countries.

The bureau pointed out that stocks of finished and unfinished gasoline on March 31 totaled 103,710,000 barrels, while statistics of the American Petroleum Institute indicate an increase of about 800,000 barrels during April, which would bring them to about 104,500,000 barrels at the close of that month, or about 17,000,000 barrels higher than last year. A reduction of 6,200,000 barrels was estimated for the coming month, compared with an actual decline of 3,947,000 barrels in June, 1939.

"Whereas it is usually necessary to intensify refinery operations during the summer to supply the greater motor-fuel demand, that need is not present this year," the report observed.

With benzol and direct sales of natural gasoline estimated at 1,200,000 barrels refinery production would be 48,200,000 barrels, which the bureau allocated among the several districts, as follows:

East Coast, 6,440,000 barrels; Appalachian, 1,930,000 barrels; Indiana-Illinois, 9,560,000 barrels; Oklahoma, 2,730,000 barrels; Kansas, 2,520,000 barrels; Inland Texas, 3,510,000 barrels; Texas Gulf Coast, 11,830,000 barrrels; Louisiana Gulf Coast, 1,430,000 barrels; Inland Louisiana - Arkansas, 860,000 barrels; Rocky Mountain, 1,290,000 barrels, and California, 6,100,000 barrels.

Natural gasoline to be blended at refineries is estimated as 5.4 percent of the total refinery gasoline production, or 2,600,000 barrels. The yield of straight-run and cracked gasoline, in order to permit the accumulation of heating oil, is estimated at a low point of 43.5 percent. The application of this yield to the production of 45,600,000 barrels of gasoline gives crude runs of 104,810,000 barrels, or 3,493,700 barrels daily. Foreign crude runs are estimated at 2,800,000 barrels.

Crude oil exports are placed at only 4,600,000 barrels, 1,231,000 barrels less than actual exports in June of last year. The estimate for crude to be used for fuel and losses is 2,000,000 barrels, making the total demand for domestic crude in June 108,610,000 barrels, or 3,620,300 barrels daily.

Bureau Allocations

State	June	May
Texas	1,344,600	1,344,200
California	593,700	592,600
Oklahoma	408,600	408,100
Illinois	395,600	392,900
Louisiana	274,700	264,500
Kansas	159,000	158,100
New Mexico	106,700	103,900
Wyoming	73,000	72,900
Arkansas	66,700	64,500
Michigan	62,000	63,200
Pennsylvania	49,400	52,100
Montana	18,300	17,400
Kentucky	15,000	14,500
New York	14,000	14,900
West Virginia	11,000	10,000
Ohio	9,000	9,800
Indiana	8,000	8,100
Mississippi	7,000	5,800
Colorado	4,000	3,500
Total	3,620,300	3,601,000

Liquefied Gas Exposition

As part of the annual meeting of the Pacific Coast Section of the Liquefied Petroleum Gas Association, Santa Barbara, California, June 27-28, the first annual Pacific Coast Liquefied Petroleum Gas Exposition will be held. While exhibit space is limited to members, attendance will be open to all interested in the industry. The exposition will provide a cross section of the latest equipment, domestic appliances and fuel-consuming applications. There will be a program devoted to subjects within the industry.

Superintendent Is Retired

Perry Ratliff, superintendent of the Dunn gasoline plant, Cromwell, Oklahoma, for The Carter Oil Company, retired from active service May 1. His employment record consisted of 41 years, 4 months and 10 days. He was 58 years old at the time of his retirement, being the only Carter employe to hold a 40-year service button. He joined the firm on April 1, 1898, at the age of 16.

READABLE.. *Anywhere!*

Out-of-reach doesn't mean out-of-reading range when WESTON Industrial Thermometers are used. Their large, gauge-type faces with bold scale markings are easy to read . . . *and read accurately* . . . a good distance away. That's why you see so many WESTONS on overhead lines, and on equipment in hard-to-get-at locations. In addition, the rigid, all-metal construction of these modern thermometers makes installation easy . . . reduces breakage losses . . . and prevents damage from over-temperatures. Available in sizes, ranges and stem lengths to meet most industrial temperature requirements. Be sure to send for catalog. Weston Electrical Instrument Corporation, 655 Frelinghuysen Avenue, Newark, N. J.

WESTON
GAUGE-TYPE . . . ALL METAL
THERMOMETERS

Military Oil Supply Ample

Army and Navy officers have been informed that the petroleum industry is prepared to meet any demands that may come to it through plans for national defense as outlined by the President in his recent message to the Congress and his radio talk to the nation. In the conferences the industry was represented by William R. Boyd, Jr., American Petroleum Institute; Fayette B. Dow, National Petroleum Association; and Russell B. Brown, Independent Petroleum Association of America.

The group informed Army and Navy department officials that the industry is better prepared than ever before to meet the increased demand for oil products that may result from the proposed expansion of the national defense.

Among the factors contributing to this preparedness are trained personnel familiar with the operations of the industry, and a greater amount of known underground reserves than at any previous time in history.

It was explained that an adequate labor supply is very important because the activities of the industry are so varied and widespread as to make difficult the training of new men whose inexperience might prove expensive. The refinery capacity of the industry, government officials were told, is sufficient to take care of any immediate increase in demand, and can be added to more rapidly than new machinery requiring petroleum products can be manufactured.

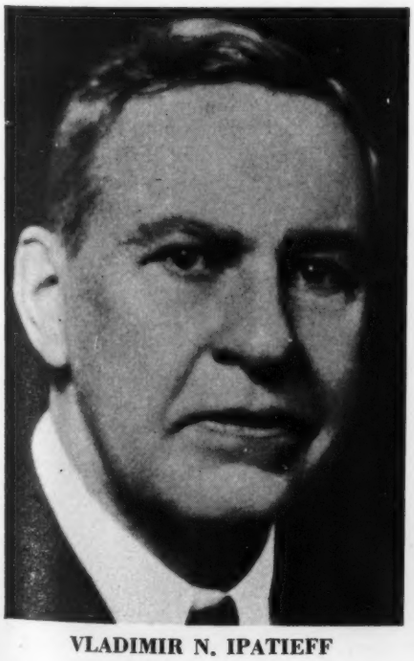
Gibbs Medal to V. N. Ipatieff

Professor Vladimir N. Ipatieff, director of chemical research for Universal Oil Products Company, Chicago, was awarded the Willard Gibbs medal by the Chicago section of the American Chemical Society May 24. The presentation was made by Professor S. C. Lind, University of Minnesota, president of the American Chemical Society. Cary R. Wagner, chairman of the Chicago section and chief chemist of The Pure Oil Company, presided, and spoke on the origin and significance of the medal. Professor Paul Haensel, Northwestern University, spoke on "Ipatieff, the Man." Gustav Egloff, director of research for Universal Oil Products Company, spoke on "Ipatieff and His Chemical Achievements."

Professor Ipatieff is inventor of the U. O. P. catalytic polymerization process. He is the author of "Catalytic Reactions at High Pressure and Temperature," published in 1936, and has contributed more than 200 scientific articles and monographs. More than 50 patents have been issued to him in the United States.

Recently he contributed $21,000 to endow a chair of high pressure chemical synthesis at Northwestern University, where he teaches. Universal Oil Products joined him in the bequest by furnishing equipment for the laboratory, which will bear his name.

Dr. Ipatieff was born in Moscow in 1867, and began his study of high pressure reactions more than 40 years ago. He has been honored by numerous European universities. Recently he was elected a member of the National Academy of Sciences of the United States.



VLADIMIR N. IPATIEFF

H. William Clute has organized Clute Petroleum Company, Tulsa, to engage in the marketing of natural gasoline. For the past three years he has been in charge of gasoline sales for Sinclair Prairie Oil Company.

18 YEARS' STAINLESS STEEL CASTING EXPERIENCE BACK UP . . .

DURALOY

TUBE SUPPORTS

Stainless steel for oil refinery equipment parts is only as good as the castings themselves. That's why experience counts so much and since the early days of stainless steel casting much has been learned to improve castings and thus enhance the value of this metal as a resistant to high temperature and corrosion.

Tube Supports are but one of the many Duraloy items made for oil refineries, but they are typical. Our experienced metallurgists, specialists in stainless steel and working with modern electric furnaces, heat-treating plant and machine shop, are in position to help select the proper analyses for your problems and to produce any size or shape of casting to meet your problem of high temperature, corrosion, or abrasion.

THE DURALOY COMPANY

OFFICE AND PLANT: SCOTTDALE, PA.

EASTERN OFFICE: 12 EAST 41ST ST., NEW YORK, N. Y.

DETROIT — The Duraloy Co. of Detroit

PHILADELPHIA — Adair-Day Corporation

SCRANTON, PA. — Coffin & Smith

ST. LOUIS — Metal Goods Corporation

LOS ANGELES — Great Western Steel Company

Chemical Award to Dr. Gustav Egloff

Dr. Gustav Egloff, director of research for Universal Oil Products Company, Chicago, received the 1940 award of the American Institute of Chemists. Presentation was made May 18 at the annual meeting, Atlantic City, by Robert J. Moore, institute president.

The award was made because of Egloff's contributions to the refining and treating of gasoline, for the number of books and technical articles he has written, his patents relating to petroleum refining processes and for service to the advancement of chemists.

Conversion of Petroleum

Under this title, A. N. Sachanen deals with the methods of producing motor fuels by both thermal and catalytic processes. His estimate of the current position of the two methods is:

"Unquestionably, thermal cracking retains its position and remains thus far the most important process among the aforementioned methods of conversion. On the other hand the part played by the other methods becomes of more and more importance, particularly in the production of high octane fuels."

The author handles his subject by first dealing with the reactions of hydrocarbons under both thermal and catalytic cracking, a discussion of the chemical composition of cracking stocks.

The several processes of conversion by both types of cracking are discussed and presented by illustrations under the chapter, "Fundamental Factors of Cracking." Both charging stocks and products are here considered.

Hydrogenation is treated in one chapter, which deals with the temperature-pressure conditions of hydrocarbons.

Products from cracking both gasoline and other finished material, along with treatment for gasolines, complete the work of 398 pages, plus index.

The book is published by the Reinhold Publishing Company, 330 West 42 Street, New York, and can be bought through The Gulf Publishing Company, P. O. Box 2811, Houston, at $6.00 a copy.

"This Fascinating Oil Business," by Max W. Ball

Drawing from a 30-year record in technical and executive positions and as a consultant to the industry, Max W. Ball has included something about everything and everything about the important features of the petroleum industry's operations and history in his "This Fascinating Oil Business."

Told refreshingly in highly readable, non-technical language which on every page seeks to make every phase of the oil business human and understandable to those who know nothing about it, and at the same time interesting and useful to those in the industry, this book has all the glamor of the best-selling novel.

The 18 chapters have more than 400 sub-chapter heads. From "crustal movements" to "the term of the lease" to "naming the well," to "treating cut oil," to "making lubes," to "anesthetics," to "freedom of the seas," these sub-chapters in one, two, or a dozen paragraphs highlight the specific subject.

Emphasized throughout are the contributions of the industry to the world's welfare, and the advances which continually are taking place in the operations and technique of the industry. Two chapters particularly offer data rarely heretofore assembled as completely, "New Worlds to Conquer," the story of petroleum research, and "Oil and the War," an up-to-the-minute analysis of the current situation. The latter received widespread publication in a recent issue of "Readers Digest."

The book, which numbers 444 pages and is well illustrated, may be obtained from the Book Department of The Gulf Publishing Company, Houston, at $2.50 a copy.

WE READ WATER

Every drop of water has a story to tell us. We know how to read it and answer the many difficulties it is bringing your plant. The story tells a battle against efficiency . . . corrosion, scaling, too much of this chemical, too little of that. We read it, tell the answer, and have the organic chemicals to correct your condition.

Known throughout the Nation are these Haering products . . .

Chrom Glucosates — *For Corrosion Prevention*
Beta Glucoside — *For Scale Prevention*
Sodium Glucosate — *For pH Adjustment*
H-O-H Feeders — *For Accurate Proportioning*
Sulpho Glucosates — *For Oxygen Removal*
Pyro Glucosate — *For High Pressure Boilers*

Our laboratories in Chicago, Wichita, Kansas, and New York City serve you over-night. Send us your water problems; or write for our bi-monthly house organ "H-O-H Lighthouse."

Have you investigated IN-HIB-CO, our new corrosion resistant coating?

D. W. HAERING & CO., Inc.
2308 S. WINCHESTER AVE.
CHICAGO, ILL.

PLANT ACTIVITIES

Grapeland Plant: Gasoline Production Company has let contracts for construction of a recycling plant, under license from the Distillate Engineering & Processes Company, in the Grapeland field, Houston County, Texas. The H. B. Zachery Company, San Antonio, has the construction contract. The plant will be built in accordance with design of the Eureka Process Company. Bethlehem-International Supply Company will provide most of the materials and equipment.

This will be the third recycling plant for the Grapeland field, and the seventh licensed to operate under Depco patent rights.

Texas Recycling: The Texas Railroad Commission last month approved applications to construct recycling plants in three fields and to conduct repressuring operations in a fourth. Shamrock Oil & Gas Corporation and Lone Star Gasoline Corporation will build a plant in Opelika field, Henderson County; Hamman Exploration Company will recycle in the Hamman field, Matagorda County; Davis & Company will build a recycling plant in the Tom Graham field, Jim Wells County, and Republic Production Company and Houston Oil Company will conduct repressuring operations in the Joe's Lake field, Tyler and Jasper counties.

Boost at Fort Worth: Magnolia Petroleum Company announced plans for a $2,000,000 modernization program for its Fort Worth refinery, which will boost capacity from 5,500 to 20,080 barrels daily. Completion is scheduled by February 1, 1941.

Casinghead in Terrebonne: United Gas Company and Humble Oil & Refining Company will build a casinghead gasoline plant in the Lirette field, Terrebonne Parish, Louisiana. The plant will also process gas for commercial use.

San Salvador Recycling: Gulf States Oil Company and associates last month tested gas and condensate reserves in the San Salvador field of Hidalgo County preparatory to construction of a recycling plant.

Partnership to Corporation: D. H. Byrd, Jack Frost, J. F. Lucey and Ralph E. Fair, who formerly operated as a partnership under the name of Talco Asphalt and Refining Company, have transferred their business at Mt. Pleasant, Texas, to Talco Asphalt & Refining Company, a corporation organized under the laws of Texas.

Wisconsin Plant: Wisconsin Oil Refining Company will start construction this month of a refinery at Sheboygan, Wisconsin. John A. Crawford is superintendent for the company.

Cities Service Oil Company on June 1 moved its refining division headquarters from Tulsa to Bartlesville, Oklahoma. Thirty-six families made the transfer.

WHAT WILL TAYLOR'S PRE-ACT DO FOR YOU?

Stop those costly, sudden control disturbances. Try this new Taylor Fulscope Control effect based on* rate *of control-point deviation.

PRE-ACT, Taylor's unique *new* control effect, is available with both *Adjustable Sensitivity* and *Automatic Reset* types of the great new Fulscope Controller. It reduces the over-peaking and oscillating which sudden control disturbances have been causing you on continuous processes that involve both long time lags and large capacities. The reason-why is apparent: Pre-Act brings about an immediate, relatively larger valve action based on *rate* of control-point deviation.

You may get Pre-Act as a standard, fully adjustable unit assembly which may be incorporated in the new Recording or Indicating Taylor Fulscope Controllers, either originally or when you desire to.

Ask the Taylor man for full details TODAY. Or write Taylor Instrument Companies, Rochester, N. Y. Plant also in Toronto, Canada. In Great Britain: Short & Mason, Ltd., London, England.

These Design Features of the New Taylor Fulscope Controllers Insure Consistently Better Performance

Automatic Reset (in the instrument case)—Fully and continuously adjustable over a much wider range, permitting the one correct adjustment your specific requirements demand. Simply, precisely constructed for even performance and easy maintenance.

Fully Pneumatic Sensitivity Reduction—Gives you consistent performance throughout the wider sensitivity range; minimizes the effects of instrument friction; and automatically compensates for fluctuations in air supply pressure. Pen movement and output pressure have a close linear relationship that insures better control on difficult applications. What's more, you may vary the controller sensitivity throughout the entire range with negligible changing in output pressure and without disturbance to the control point.

Universal Application— Same control mechanism for temperature, pressure, rate of flow, and liquid level in recording and indicating controllers. (Temperature and pressure recording controllers are available in double-duty form.)

Quick-Change Unit Construction—No soldered joints, no screws to drop. Cases drilled and tapped to accommodate most complete forms of control and to enable you to maintain easily and change from one form to another in the field.

Pre-Calibrated Actuating System—More easily interchangeable than ever.

Magnifying Adjustment Dials—Easier to read and adjust; calibrated in absolute units.

Easy Convertibility— From direct to reverse action.

Universal Case— Made of die-cast aluminum for face or flush mounting.

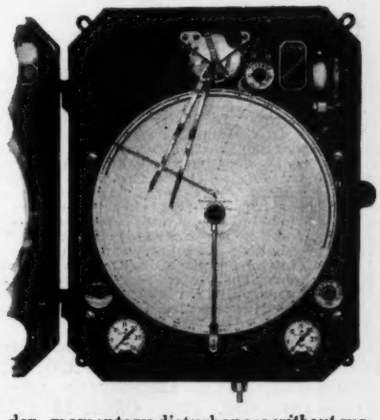
Electric Chart Clocks—Redesigned, with improved coils, oil-immersed gears and slower speed motors. Spring-driven clocks an alternate. Explosion-proof electric clocks also available.

Inbuilt Air Filters—Easy to clean, more efficient and accessible. They supplement large filter and drip well.

Quicker Chart Changing—Separate pen lifter and hub nut eliminated.

Accessibility—Dials and knobs instantly accessible without removing chart and chart plate.

Longer Life—All vital parts of 18-8 stainless steel. Neoprene gaskets throughout.



Only the New Taylor Fulscope Controller gives you these

5 FORMS OF CONTROL

Fixed High Sensitivity—for on-and-off control on applications with small time lags and large capacities, regardless of load changes.

Adjustable Sensitivity—for throttling control on applications with a wide range of time lags and capacities, where there are infrequent or minor load changes.

Adjustable Sensitivity with Automatic Reset (in same case)—for precision control on applications involving a wide range of time lags and capacities, with gradual, sustained load changes.

Adjustable Sensitivity with Pre-Act—for applications with a wide range of time lags and capacities, where there are sudden, momentary disturbances *without* sustained load changes.

Adjustable Sensitivity with Automatic Reset and Pre-Act—for ultimate precision control on applications involving a wide range of time lags and capacities *with* sudden and sustained load changes. The Fulscope Controller, with all three effects, can be adapted to almost any of your control problems.

Taylor

Indicating / **Recording • Controlling**

TEMPERATURE, PRESSURE, FLOW *and* LEVEL INSTRUMENTS

SCIENCE AND TECHNOLOGY

Abstracts prepared in co-operation with the

REFINER AND NATURAL GASOLINE MANUFACTURER

by

THE LESLIE LABORATORIES

Traver Road, Ann Arbor, Mich.

under the supervision of

DR. E. H. LESLIE and DR. H. B. COATS

The abstracts here presented are selected from the current literature of science and technology to afford reference to fundamental information not easily available to all readers. Abstracts of articles appearing in readily obtainable trade journals are not included. Photostat copies of original articles will be supplied at cost by the Leslie Laboratories. Complete or limited bibliographies covering special topics by title, by abstracts, or in complete manuscript, will also be prepared and furnished at reasonable cost by the Laboratories.

Chemical Compositions and Reactions

Identification of Paraffins, A. V. GROSSE, E. J. ROSENBAUM AND H. F. JACOBSON, *Ind. & Eng. Chem.,* Anal. Ed. **12** (1940) pp. 191-4.

The identification of the paraffin hydrocarbons has increased in importance as a result of the catalytic synthesis of these hydrocarbons from olefins and paraffins. The method described by the authors is based on the determination of the Raman spectrum of a narrow-boiling fraction. Charts are given showing the Raman spectra of the hexanes and heptanes. The method is described, and typical results are presented. The procedure has been applied to the identification and approximate quantitative analysis of the paraffins up to and including the oxtanes.

The Separation of the Isomeric Hexenes by Batch Fractionation, A. ROSE, *Jour. Am. Chem. Soc.* **62** (1940) pp. 793-5.

In order to estimate the maximum possible sharpness of separation for any pair of substances it is necessary to know the vapor pressure ratio (alpha) for the pair. Values of alpha are given for several pairs of hexenes. Calculations were made that show that a minimum of 400 or more theoretical plates are required for the sharp separation of certain close boiling hexenes, and that the use of a fractionating column with a small number of theoretical plates can produce no appreciable separation in such cases even with a low column holdup and a high reflux ration.

Condensation of Olefins and Paraffins by Means of Sulfuric Acid, H. I. WATERMAN, J. J. LEENDERTSE AND R. HESSELINK, *Rec. Trav. Chim.* **58** (1939) (In English) pp. 1040-7.

Branched pentanes and pentenes were condensed at 0-9° C., using sulfuric acid as a catalyst. Based on the olefins, yields of 177% were obtained, and the products formed ranged from isobutane to high boiling substances. Little unsaturation remained in the products. No cyclic compounds were formed. Best results were obtained when the pentane to pentene ratio was 3:1. The catalyst was stable, and was used 7 times with no decrease in activity. The reaction probably takes place in several stages, first the preliminary condensation of olefins and paraffins, then a partial destruction, and then a further condensation between the newly formed products.

Conversion of Naphthenic Acids to Naphthene Hydrocarbons, G. E. GOHEEN, *Ind. & Eng. Chem.* **32** (1940) pp. 503-8.

The naphthenic acids used in this investigation were from Gulf Coast crude oil and were similar to the acids studied by Harkness and Bruun. A fraction of the acids isolated from the lubricating oil portion of the crude was investigated in detail. This fraction had an average molecular weight of 317 and an average molecular formula of $C_{20.7}H_{35.2}O_{2.1}$. In order to prepare the corresponding naphthene hydrocarbons from the acids the ethyl esters of the acids were made. These esters were reduced to alcohols, and these in turn converted to the naphthene iodides. The naphthenic iodides were reduced to the corresponding naphthenes by treatment with gaseous hydrogen chloride and zinc dust in glacial acetic acid. The naphthene hydrocarbons so prepared were found to have higher viscosity indices than those of a typical naphthene-base oil. Evidence was obtained indicating that the acids were monobasic compounds containing an average of 2.6 rings per molecule. No more than approximately 5 per cent by weight of aromatic material was present.

Naphthenic Acids from Gulf Coast Petroleum, R. W. HARKNESS AND J. H. BRUUN, *Ind. & Eng. Chem.* **32** (1940) pp. 499-502.

The term "naphthenic acids" describes the cyclic carboxylic acids occurring in and obtained from petroleum. Until recently the commercial naphthenic acids have been extracted only from the kerosene and gas oils. Recently the naphthenic acids from lubricating oil fractions have become commercially available. The naphthenic acids studied by the authors were the heavy acids from Gulf Coast crude oil. Their separation and purification are described. A molecular still was used for the purpose in order to avoid decomposition. The naphthene acids in the lubricating oil portion of a Gulf Coast petroleum were found to have a molecular weight of 220-440, corresponding to 14-29 carbon atoms per molecule. The hydrogen deficiency below the fatty acid series is 4-10 atoms per molecule. This is not caused by simple unsaturation but is occasioned by the presence of naphthenic rings and possibly aromatic rings. If aromatic rings are absent, at least five naphthene ring closures are indicated in each molecule of these acids. The acids are at least substantially monobasic.

Naphthenic Acids, J. R. M. KLOTZ AND E. R. LITTMANN, *Ind. & Eng. Chem.* **32** (1940) pp. 590-1.

Aruba naphthenic acid is extracted from Colombian gas oil with dilute sodium hydroxide and recovered from the alkaline solution by acidification. The acid so obtained was distilled under reduced pressure into several fractions. The phenol content of each fraction was determined. It was found that the phenols were contained mainly in the low- and high-boiling ends of Aruba acid. The inhibitory effect of the phenols in the naphthenic acids was studied. This is of particular interest when the acids are used in making driers. It was found that although the acids themselves in some instances inhibited the oxidation of benzaldehyde, in the presence of manganese naphthenate drier the inhibitory effect not only disappeared but changed to a catalytic action. The acid numbers of the acids were studied, and it was concluded that the acid number has little value as a criterion for the purchase or evaluation of naphthenic acids.

Phenolic Compounds from Petroleum Sources, E. FIELD, F. H. DEMPSTER AND G. E. TILSON, *Ind. & Eng. Chem.* **32** (1940) pp. 489-96.

Cresylic acids from petroleum are receiving wide recognition as germicides, fungicides, and disinfectants. They are the equal of coal tar acids from the standpoint of quality. The acids are also finding increased use as dormant spray material for orchard use, and as an addition in ore flotation. The cresylic acids are extracted by scrubbing cracked petroleum naphtha with sodium hydroxide solution, acidifying the caustic extracts, separating the phenolic substances and purifying them. The authors review the literature pertaining to phenolic substances in petroleum and give a detailed description of their investigation on light, medium, and heavy grades of these compounds. The physical, chemical, and germicidal properties are given, each grade having been refractionated into 3° C. cuts. These various close cuts were finally analyzed for individual phenolic compounds, the analyses being as nearly quantitative as possible. The lighter grades of acids from petroleum are composed mainly of cresols and xylenols. The heavier grades contain cresols and xylenols in small proportions, and are mainly composed of higher phenolic homologs. Petroleum acids as separated are characterized by containing large amounts of individual compounds. This makes them an excellent source from which to recover individual phenols. These individual phenols are useful as raw materials in the synthetic plastic industry, and for other purposes.

Products: Properties and Utilization

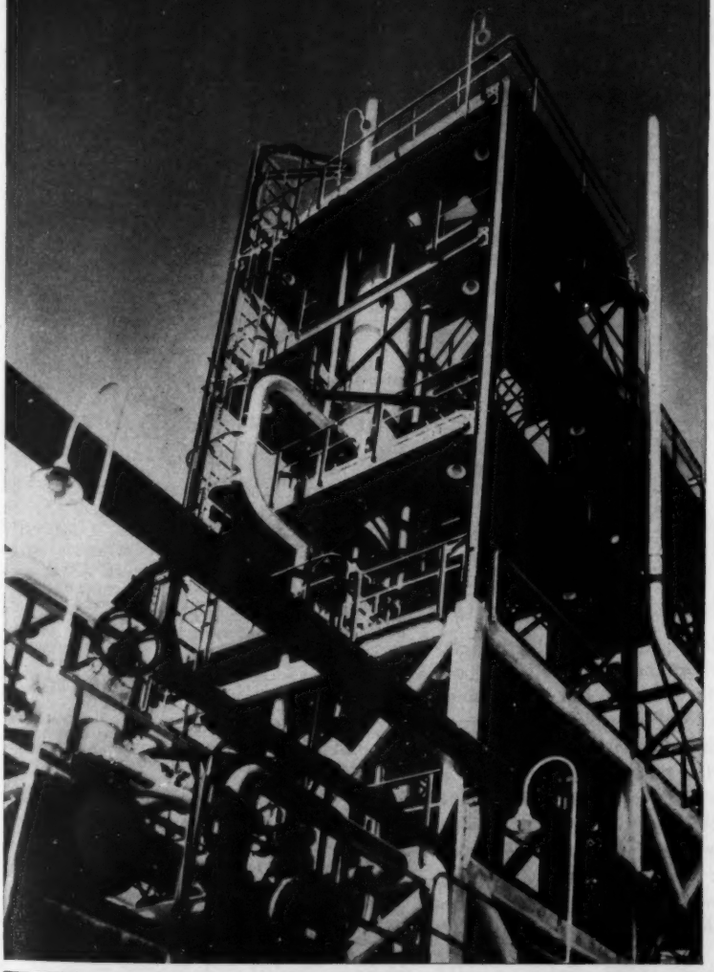
Development of Rancidity in Stoddard Dry Cleaning Solvent, A. C. SMITH, C. S. LOWE AND G. P. FULTON, *Ind. & Eng. Chem.* **32** (1940) pp. 454-60.

The elimination or less frequent use of alkali treatment and vacuum distillation in the recovery of dry cleaning solvents, and the substitution therefor of pressure filtration alone, necessitates the study of the development of rancidity in Stoddard dry cleaning solvent. The increase in the fatty acid content of the solvent was found to be caused largely by free fatty acids from soap added to the solvent, rather than to fatty acids present in the soil from the garments. The Kreis test, in modified form, has been found useful in detecting incipient rancidity. Peroxides formed during the cleaning operations decomposed in the drying cabinet and formed aldehydes and low-molecular-weight acids. Potentiometric titration curves on residues from used dry cleaning solvent show the buffering effect of these decomposition products. The sulfuric acid absorption test, on which many dry cleaners have relied for checking the condition of their solvent with respect to rancidity, has been shown to be unsuitable for the purpose.

Detergents from Kerosene, A. R. PADGETT WITH ED. F. DEGERING, *Ind. & Eng. Chem.* **32** (1940) pp. 486-8.

A kerosene fraction from mid-continent petroleum and boiling at 95-100° C. at 15 mm. absolute pressure was chlorinated to yield 85 percent of the monochlorides. These were converted to N, N-diethanolkerosylamine by digesting with diethanolamine for 18 hours at 185° C. The amine hydrochlorides were compared to sodium lauryl sulfate as a standard by use of the drop number test and the foam test. The results of these comparative tests indicated that the amine hydrochlorides made

Efficiently Utilizing Available Crudes



CRACKING units under license from Gasoline Products Co. embody in their design the striking advances in methods and equipment developed during the past few years in the field of pyrolytic cracking.

These units permit the refiner to utilize available crudes to produce products best suited to prevailing market conditions.

Refiners considering new plants or modernizing their present cracking facilities should carefully consider these advantages.

GASOLINE PRODUCTS COMPANY, INC.

26 Journal Square • Jersey City, New Jersey

LICENSES granted under United States and Foreign Patents for: Cross, de Florez, Holmes-Manley, Tube and Tank Cracking Processes, Uni-Coil Injection Process and Combination Cracking Units
Licensing Agents: THE M. W. KELLOGG CO., Jersey City, New Jersey, or its European Representative: COMPAGNIE TECHNIQUE des PETROLES, 134 Boulevard Haussmann, Paris, France

were less satisfactory than sodium lauryl sulfate as foaming agents. The primary compounds compare more favorably with sodium alkyl sulfate than the secondary compounds. Those produced from the kerosene fraction were the least satisfactory of all tested.

Stability of Crankcase Oils, W. F. WEILAND, *Trans. Am. Soc. Mech. Engrs.* **62** (1940) pp. 125-32.

The article is concerned with the performance and useful life of lubricating oils. Oxidation and corrosion are major factors in the deterioration of crankcase oils. The requirements for conducting oxidation tests are outlined, and the results of such tests are given. The behavior of oils in service offers a means of predicting oil performance. Acid-vapor tests for determining oil breakdown are considered and the results of corrosion studies are given in detail.

Bearing Corrosion and Diesel-Engine Lubrication, C. J. COPLEY, *Southern Power and Ind.* **58** (1940) pp. 58-62.

The newer Diesel engines operate at higher speeds, temperatures and compression ratios than in the past. As a result, new bearing metals have been necessary. More severe operating conditions cause more rapid oxidation of the lubricating oil, resulting in acid formation and corrosion of the bearings. This can be eliminated by the use of addition agents added to the oil. Other desired characteristics of Diesel-engine lubricating oils can be secured by compounding. A straight mineral oil is not suitable for the lubrication of modern Diesel engines.

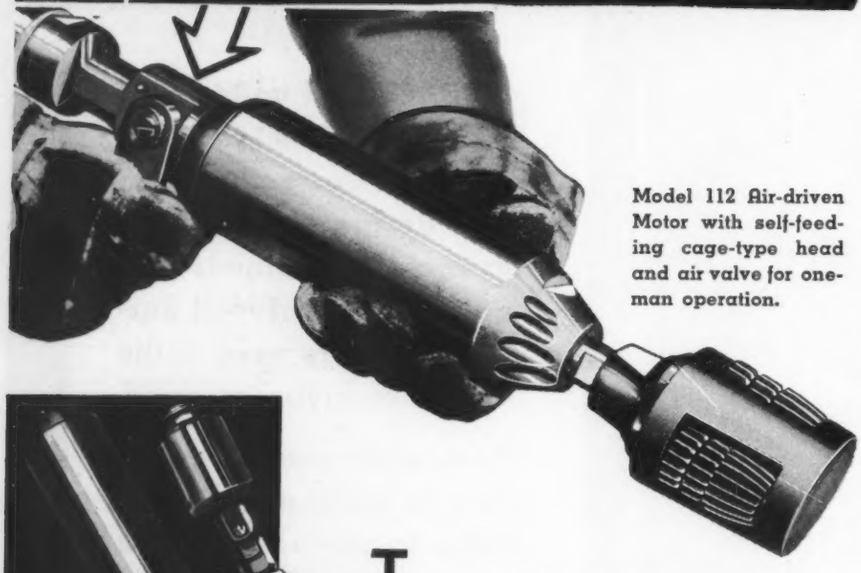
Asphaltic Bitumen as Colloid System, J. PH. PFEIFFER AND R. N. J. SAAL, *J. Phys. Chem.* **44** (1940) pp. 139-49.

The authors found little difference between the carbon/hydrogen ratios of the asphaltenes of steam-refined and blown asphalts. The values varied from 0.8 to 0.9. The asphaltenes from cracked residues showed ratios up to 1.3. Through study of the rheological properties of synthetic bitumens prepared in the laboratory, making use of a coni-cylindrical rotation viscometer, it was found that the tendency of asphaltic bitumens to form gel structures is not observed in the presence of an excess of aromatic malthenes. By use of a sweating process the authors studied 3 asphalts of the same penetration index but differing in asphaltene content and were able to separate the intermicellar liquid and to show that this sweated oil is practically free from asphaltenes. They conclude that at normal temperature the micelles consist of asphaltenes into which a substantial part of the malthenes may be bound, and since the quantitative ratio between the volume of the micelles and that of the asphaltenes is not constant, the quantity of asphaltenes is to be considered as only a very approximate indication of the micelle content.

The Flow Properties of Bituminous Materials, A. R. LEE, J. B. WARREN AND D. B. WATERS, *Jour. Inst. Petr.* **26** (1940) pp. 101-128.

Bituminous materials are used for a variety of industrial purposes, but most extensively in road construction. Although the paper deals with this aspect of their use, much of the information presented is of more general interest, since it is concerned with fundamental properties. Some results are given of the investigations now in progress on the fundamental flow properties of bitumens and bitumen-aggregate mixtures. A coni-cylindrical viscometer was used for measuring the effect of stress and temperature on the viscosity and elastic recovery of various types of bitumens. The relation between rate of shear (D) and the shearing stress (S) for all but the most plastic bitumens can be represented by an equation of the form $D = \left(\frac{1}{n'}\right) S^p$, where n' and p are constants. The use of the index p as a "plastic-flow index" provides a method of expressing the degree of plasticity of a bitumen, where this is considered as the divergence from ideal viscous flow. Different bitumens having the same penetration (65) may have very different viscosities. The bitumens so far investigated have been found to differ chiefly in their plastic and elastic properties. The effect of stress and temperature on the flow properties of roller-compacted specimens of bitumen-aggregate mixtures has been investigated by beam and tensile tests. The relation between stress (S) and the minimum rate of strain (R) can be expressed by the equation $R = KS^p$, where K and P are constants. The flow properties at the minimum rate of deformation under conditions of constant tensile stress can be expressed completely by a number of constants—namely, P, K_0 (the minimum rate of strain at unit stress at 0° C.) N (the rate of change of log. K with change of temperature), and the extensibility at failure, the value of these constants being determined by the nature and grading of the aggregate and by the nature of the binder. Mixtures of a particular aggregate grading containing the more plastic bitumens have greater values for P than those containing non-plastic bitumen; the value of P is affected more by the grading and proportion of the aggregate than by the nature of the bitumen.

Refiners Can Now Clean Tubes FASTER, CHEAPER, BETTER with *Rapid Action* ROTO Guns



Model 112 Air-driven Motor with self-feeding cage-type head and air valve for one-man operation.

THE new Rapid Action Roto Gun is the machine gun of tube cleaners. With its rapid action "trigger," a single operator can clean tubes faster than a man and helper using the old type gun. The operator himself turns the air on and off instantly, saving the time formerly wasted in signalling the helper between every one of the hundreds of tubes cleaned. New motor design makes more effective use of air consumed without developing back pressure. New self-feeding cage and swing-frame heads and other features give you a faster, cheaper and better cleaning job. Let us prove it in your own plant, as we have in others.

See Our Adv. in Sweet's Catalog

The ROTO Company

145 Sussex Ave. Newark, N. J.

Fundamental Physical and Chemical Data

Volumetric and Phase Behaviour of Hydrocarbons, B. H. SAGE AND W. N. LACEY, Pp. 299, *Stanford University Press,* California, 1939, HUMPHREY MILFORD, *Oxford University Press,* $5.00.

The application of scientific principles in petroleum technology has been retarded by lack of data, but in recent years a formidable body of experimental knowledge of the hydrocarbons has accumulated. The quantitative liquid-gas behaviour of the hydrocarbons is considered in this book, which constitutes a logical and scientific treatment of the subject. The book opens with an introductory chapter covering general definitions and phase equilibria, followed by a chapter on the mathematical concepts involved. The one-component system is next considered in the order, gases, liquids, two-phase region, and critical region. In the fourth chapter, two-component systems are considered in the order, single-phase region, two-phase region and three-phase region. The discussion of three-component systems is largely concerned with liquid-gas phase behaviour, and constitutes the most comprehensive description of this subject so far published. The chapter on multi-component systems describes their behaviour in the light of experimental data available on such diverse materials as natural gas, gasoline, crude oil, and natural gas-crude oil mixtures. In other chapters such subjects as the phase rule, partial quantities, ideal solutions, and retrograde condensation are considered. Many of the 194 illustrations in the book are presentations of quantitative data with references to the original data in the literature.

The Vapor Pressures of Certain Unsaturated Hydrocarbons, A. B. LAMB AND E. E. ROPER, *Jour. Am. Chem. Soc.* **62** (1940) pp. 806-14.

Careful measurements were made of the vapor pressures of very pure samples of liquid

A new standard

It's 72-74 octane rating now for house brand gasoline—that's the new standard (Motor method) of the Western Petroleum Refiners' Association

How much those two extra numbers cost refiners depends on how high octane they can make in the plant, consistent with good yield, and how much they have to buy

Dubbscracking makes the biggest yield of high octane gasoline from any charging stock and at lowest cost

U. O. P. catalytic polymerization increases the yield and boosts the octane rating still more

Universal Oil Products Co
Chicago, Illinois

Dubbs Cracking Process
Owner and Licensor

ethene, propene, 2-methylpropene, 1-butene, cis-2-butene, trans-2-butene, 1,4-pentadiene and 2-methyl-2-butene over the range from 10 to 1000 mm. pressure. Equations with three constants were derived by the method of least squares that expressed vapor pressure as a function of the temperature. The vapor pressure of liquid and of crystalline propadiene and its triple point temperature and pressure were also determined. From the least square equations the normal boiling points and the slopes of the vapor pressure curves as well as the heats of vaporization of the substances were computed. In general, the vapor pressures were found to agree well with the Ramsay-Young and the Duhring rules, particularly when in each rule an additional constant is introduced. A general equation was derived expressing the temperature differential of the vapor pressure at the boiling point as a function of the absolute boiling point. The data were found to be in excellent agreement with this equation. The apparatus and procedure are described in some detail, and the results are presented in tabular form.

Vaporization Equilibria, M. GILBERT, *Chem. & Met. Engr.* **47** (1940) pp. 234-5.

The lengthiness of solutions to problems in equilibrium vaporization for multi-component mixtures makes graphical methods desirable. Although some computations cannot be avoided, the graphical method described by the author minimizes this computation. The mathematics of the method is presented, and an illustrative calculation is given. Two charts are included in the article. It is contended that the accuracy of the method, as well as its saving of time, make it more desirable than many trial and error procedures ordinarily used.

Calculation of Boiling Points of Aliphatic Hydrocarbons, C. R. KINNEY, *Ind. & Eng. Chem.* **32** (1940) pp. 559-62.

The calculation of the boiling points of the aliphatic hydrocarbons can be accomplished by use of the boiling point equation previously developed. The method depends upon obtaining sufficient accurate boiling point data so that the boiling point number may be obtained for the various structural groupings. From the existing data for the aliphatic hydrocarbons it is possible to obtain the necessary boiling point numbers and to calculate the boiling points of these hydrocarbons, including the naphthenes, from their structures. Also, the structure of a hydrocarbon can be calculated from its boiling point and molecular formula, but for the higher hydrocarbons that have many isomers, several structures have the same molecular boiling point number. However, in spite of this, the use of boiling point data definitely limits the possible structures that a hydrocarbon boiling at a particular temperature can have. The method of procedure is described in some detail, and is applied to paraffins, olefines, acetylenes, and naphthenes.

Viscosity of Hydrocarbon Solutions, B. H. SAGE AND W. N. LACEY, *Ind. & Eng. Chem.* **32** (1940) pp. 587-9.

The effect of pressure on the viscosity of hydrocarbon liquids has been studied by several investigators, and also the effect of dissolved gas on the viscosity of these liquids. However, previous results involve the combined effect of the change in composition and the change in pressure. In the present work these effects were separated so that it was possible to ascertain individually the effect of changes in pressure and in composition upon the viscosity of hydrocarbon liquids. The viscosity of 21 liquid mixtures of methane, ethane, and crystal oil was determined at pressures between bubble-point pressure and 2500 pounds per square inch at a temperature of 100° F. Information with respect to the viscosity of the liquid phase of these mixtures in the two-phase region was also obtained. The results secured in the work are presented in detail in tabular and graphical form.

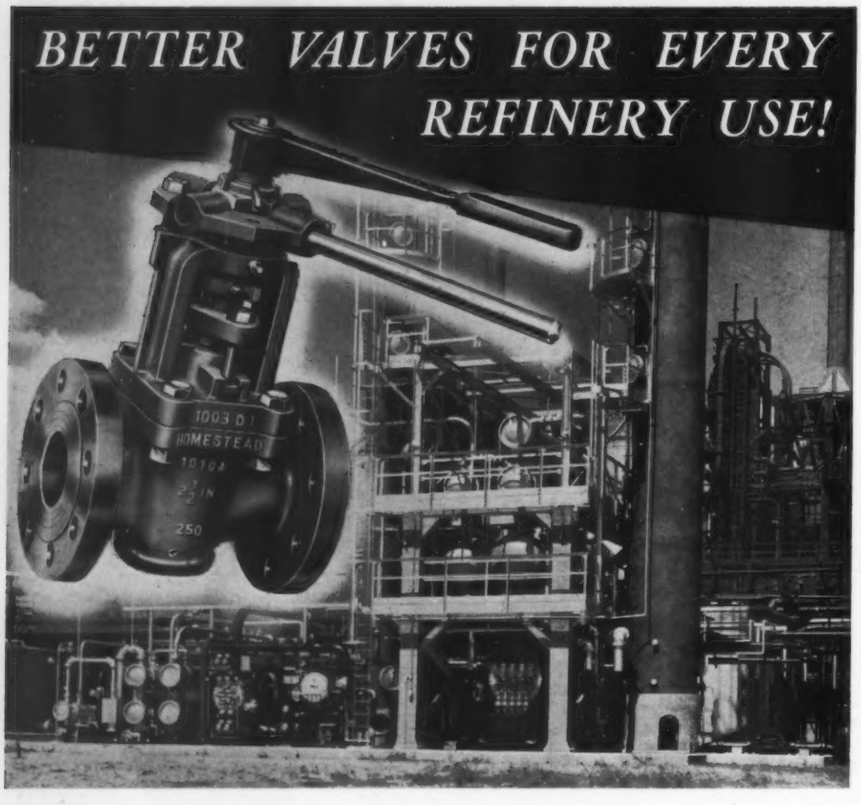
Manufacture: Processes and Plant

Industrial Synthesis of Hydrocarbons from Hydrogen and Carbon Monoxide, A. J. V. UNDERWOOD, *Ind. & Eng. Chem.* **32** (1940) pp. 449-54.

The development of the industrial synthesis of hydrocarbons from hydrogen and carbon monoxide is briefly reviewed. The most effective catalysts are cobalt, nickel, and iron. In the present commercial installations a cobalt catalyst with a promoter, supported on kieselguhr, is used. The reaction is effected at 190-200° C. The maximum yield is obtained at pressures between 5 and 15 atmospheres. Data are given showing the effect of pressure on the total yield and on the type of hydrocarbon produced. The variation of yield with time at various pressures is given. Raw materials used are listed, as well as the several processes for the production of the synthesis gas. In the United States the most interesting raw material for the process is methane. It is less difficult to produce the synthesis gas from methane than from solid fuels, and a smaller investment is required for equipment. The reactions and necessary plant operations are described in some detail. The products include: gasoline of low octane number, Diesel oil of high cetane number, and paraffin waxes, including high melting wax. Wax of 195° F. melting point is being produced commercially on a large scale. Methods of converting the products into gasoline of higher octane numbers are briefly discussed. Synthetic lubricating oils can be made. The most interesting aspect of the process in the United States is its possible application in the treatment of methane from natural gas, and the consequent relationship to the conservation of natural resources.

The Synthesis of Lubricating Oils by Condensation Reactions. Part 1, W. R. WIGGINS, T. G. HUNTER AND A. W. NASH, *Jour. Inst. Petr.* **26** (1940) pp. 129-145.

Only recently has the Friedel-Crafts type of reaction been utilized for the production of viscous hydrocarbons of high boiling point and of lubricating properties. Chlorinated paraffin waxes can be condensed with aromatic hydrocarbons, using metallic aluminum as catalyst to give viscous hydrocarbon oils. The oils have high viscosity indices, and the viscosity-gravity constants are in many cases comparable to those of paraffin base oils. The Conradson carbon residues of the benzene and toluene condensation oils are extremely low. All the condensation oils have good oxidation resistance. The color change upon oxidation is small, no asphalt is deposited, and the increase in viscosity is similar to that of commercial motor lubricants. The chlorinated waxes corresponding analytically to mono- and di-chloro-paraffin give condensation products that are solid at room temperature. The yield of high molecular weight material, boiling above 300° C. at 3 mm. pressure increases with increasing chlorine content of the chlorinated paraffin wax. The specific gravity, refractive index, viscosity, and viscosity-gravity constant increase with increase in the chlorine



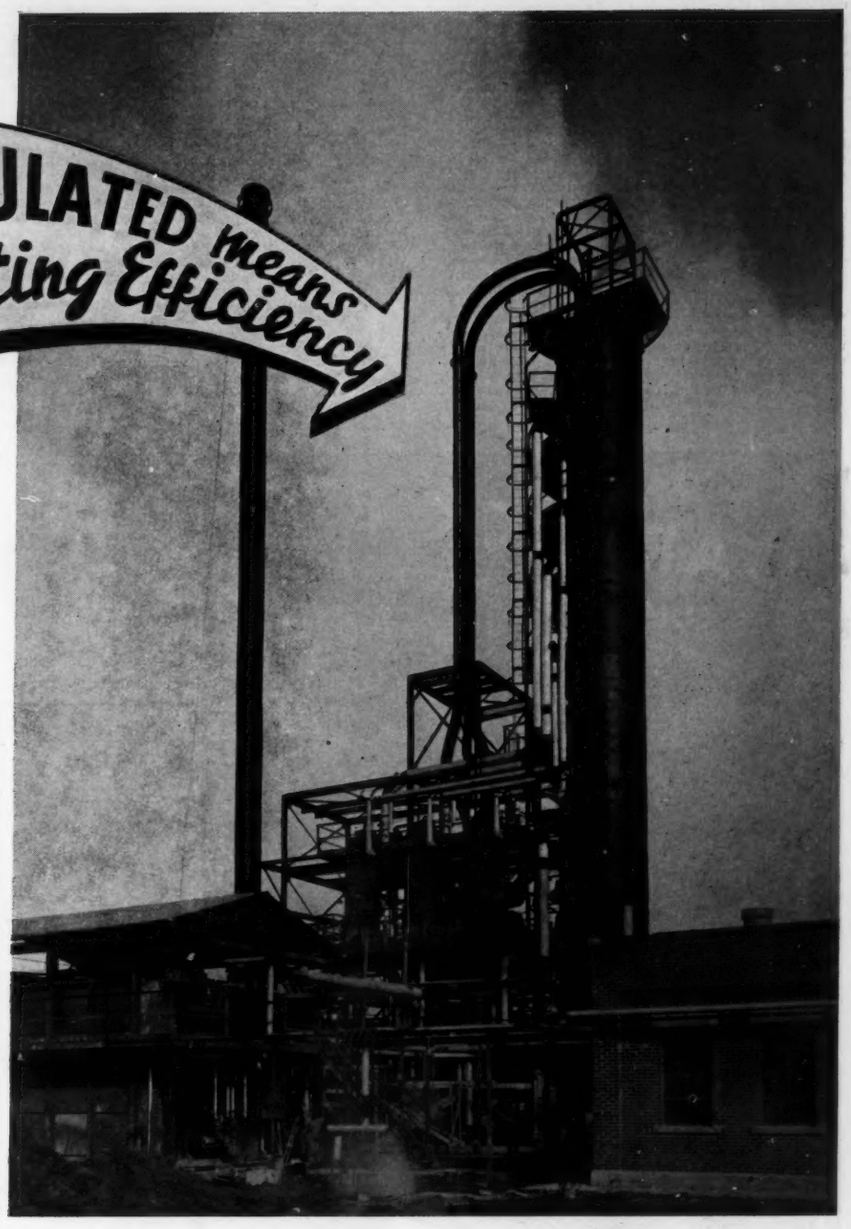
The full line of Homestead "Lever-Seald" and "Cam-Seald" Plug Valves is *specifically designed* to meet and master temperature, pressure and corrosive service conditions of the modern Refinery. Their straight-thru flow, protected seating surfaces, positive sealing, and quick operation, even under the heat and pressure conditions of Catalytic Refining, assure unusually long life with lowest maintenance. One prominent Refiner's report, that thirty 4″ and 8″ Homestead Switching Valves are still going strong after eleven years service on temperatures up to 1120°F. and pressures to 200 pounds, is typical of hundreds of records of Homesteads' low-cost-per-year valve service. It will pay you to specify "Homesteads" on your next valve order.

Send for Valve Reference Book No. 38; and for special quantity prices on your valve requirements.

HOMESTEAD VALVE MFG. COMPANY
P. O. BOX 16, CORAOPOLIS, PA.

HOMESTEAD VALVES

B-H INSULATED means Peak Operating Efficiency



BALDWIN-HILL BLACK ROCKWOOL BLANKETS
used on this
UTILITY DISTILLATION UNIT
built by
FOSTER WHEELER CORP.
for
TOLEDO REFINERY

Maximum output and more uniform temperature control are assured through the application of BALDWIN-HILL Black Rockwool Blankets. Chemically stable, the material used in fabricating these blankets does not settle, nor does it break down or decompose under the most severe heat and moisture conditions.

On the unit shown here, B-H Black Rockwool Blankets were first applied, covered with ½" coat of B-H No. 1 Insulating Cement and then protected from the weather with ¼" coat of B-H Weatherseal—meeting every insulation requirement for this type of refinery installation.

For better temperature control, higher operating efficiencies and preventable waste of power, BALDWIN-HILL offers a complete line of Heat Insulation Products . . . B-H Black Rockwool Blanket . . . B-H No. 1 Insulating Cement . . . B-H No. 100 Pipe Covering . . . B-H Insulating Block . . . B-H Weatherseal and others effective up to 2000°F.

Send for Catalog with complete data on entire line, applications, heat loss charts, insulating efficiencies, etc.

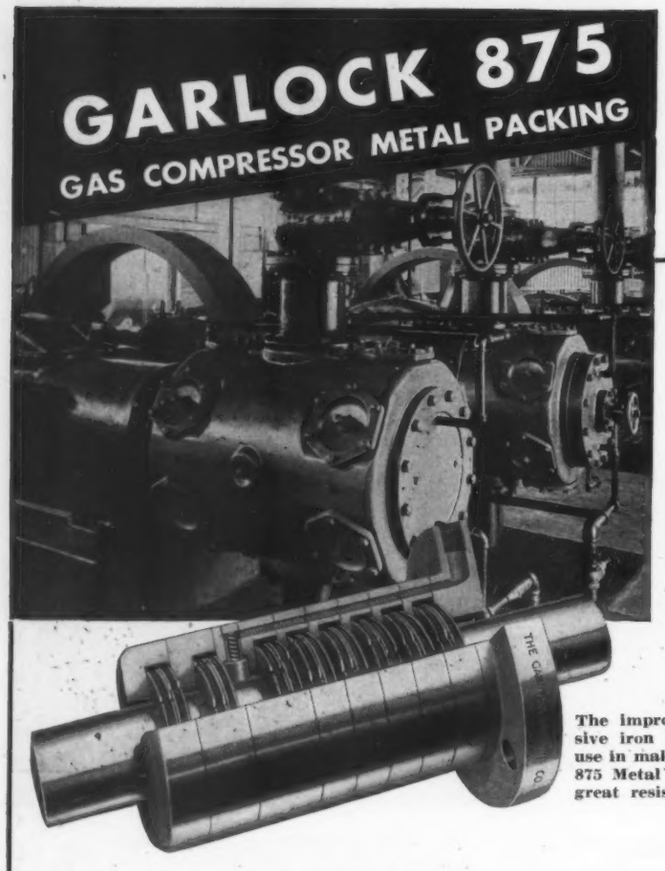
BALDWIN-HILL CO.

567 KLAGG AVE. . . . . TRENTON, N. J.

content of the chloro-paraffin component. The viscosity index and pour point decrease for the higher chloroparaffin derivatives. Naphthalene reacts less readily than benzene or toluene, and requires a longer preliminary induction period. The yields are approximately the same for the benzene and toluene derivatives, but the yield of the naphthalene oil is considerably less. The specific gravity, refractive index, viscosity, and viscosity-gravity constant increase in the order of the molecular weights of the aromatic components. The viscosity indices are fairly uniform—105-110—but the viscosities of the residual naphthalene oils above 300° C. at 3 mm. are beyond the range of viscosity-index calculations. The carbon residues of all the benzene and toluene oils are low, but the naphthalene oils have high carbon residues. The metallic aluminum catalyst gives higher yields than aluminum chloride catalyst. The latter causes the formation of excessive quantities of sludge, and in the case of naphthalene condensed with trichloroparaffin the product is a rubber-like or asphaltic material. The heavy sludge can be used as catalyst, and produces oils similar to those obtained with aluminum as catalyst, but, unless used in conjunction with the metal, the yield decreases.

Catalytic Cyclization of Aliphatic Hydrocarbons to Aromatics, A. V. Grosse, J. C. Morrell and W. J. Mattox, *Ind. & Eng. Chem.* **32** (1940) pp. 528-31.

The authors describe their method of dehydrogenating straight-chain hydrocarbons and causing the formation of cyclic or aromatic hydrocarbons. They state that they are able to convert n-Heptane into toluene with a yield of about 75 per cent of the theoretical in a single pass, or 90 per cent if recycling is used. The catalysts used are composed of oxides of chromium or molybdenum, vanadium, and titanium and cerium. These are mounted on active alumina or magnesia. The preparation of a typical catalyst is described. Experiments were made in which a large number of pure aliphatic hydrocarbons were cyclized with various catalysts under different conditions. Paraffins, mono, and diolefins, and acetylenes, were studied. For example, n-hexane and n-hexenes were converted into benzene; n-Heptane and n-heptene into toluene; n-octane and n-octene into ortho, meta- and para-xylenes and ethylbenzene. The apparatus and procedure are described, and the results of a typical run are given. A bibliography of 22 references is included.



The improved, non-abrasive iron which we now use in making GARLOCK 875 Metal Packing offers great resistance to wear.

High or Low Stage....

GARLOCK 875 Metal Packing gives long, dependable service on high or low stage gas compressors. Frequent periodic tests guarantee the uniformity of this quality controlled metal packing. Try it on *your* gas compressors.

THE GARLOCK PACKING COMPANY

PALMYRA, NEW YORK

Tulsa, Okla. Houston, Texas Los Angeles, Calif.

GARLOCK

"Rubber" from Petroleom Gases, D. North, *Chem. & Met. Engr.* **47** (1940) pp. 220-4.

Production of synthetic rubber has assumed the proportions of a major industry in the United States, Germany, and Russia. The recent announcement by the Standard Oil Company of New Jersey that it will build a plant for the production of synthetic rubber of the Buna type at Baton Rouge, Louisiana, has arounsed wide interest. All commercial synthetic rubbers are produced, in part at least, from one or from either one of two, of the following unsaturated hydrocarbons: butadiene, isobutylene, acetylene, or ethylene. Buna rubbers are derived from butadiene; neoprene is made from acetylene; Thiokol from ethylene; and vinyl chloride from acetylene or ethylene. Petroleum gases are the largest source of these various materials. The author briefly describes the method of making Thiokol, neoprene, Resistoflex, and Buna rubbers. In Standard Oil of New Jersey's new plant the raw materials will be butadiene and acrylic nitrile, which will be recovered or made from refinery gases. The Universal Oil Products Company recently announced a process for the production of butadiene by the catalytic dehydrogenation of butane to butylene, to butadiene. The Phillips Petroleum Company has been working actively on the production and recovery of butadiene. The United Gas Improvement Company, at Chester, Pennsylvania, is erecting a plant for the production of a series of unsaturated and aromatic hydrocarbons, including butadiene and styrene. The Dow Chemical Company is producing butadiene in its process for cracking petroleum to obtain ethylene. The Dow Chemical Company is the first American company to produce and sell pure butadiene. Buna rubbers are resistant to animal, vegetable, and mineral oils, but swell in aromatic hydrocarbons, ketones, alcohols and esters, and in chlorinated hydrocarbons and organic bases they swell more than natural rubber. In aging, exposure to sunlight, resistance to heat, moisture, abrasion and flexing, and in permanent set and creep, they are superior to natural rubber. Last summer, prior to exhaustion of supplies of imported Perbunan, the price in the United States was 90c per pound compared with 65c for neoprene and about 16c per pound for crude rubber. It is hoped to produce Buna rubber for a price of approximately 20c per pound in the United States. Vistanex, produced from isobutylene by the Standard Oil of New Jersey at Bayway, is briefly discussed, including its manufacture and uses. Its present cost is approaching 10c per pound, and it may become an important factor in competition with rubber.

Buna Rubbers, A. Koch, *Ind. & Eng. Chem.* **32** (1940) pp. 464-7.

In the narrower sense products basically composed of dienes, i.e. hydrocarbons closely related to isoprene, can be termed "synthetic rubber." These highly polymerized materials consist of long-chain molecules. It appears likely that in natural rubber there are approximately 2000 isoprene molecules linked or joined together, corresponding to a molecular weight of 136,000. The I. G. Farbenindustrie at the present time manufactures Buna 85, Buna S, Perbunan, and Perbunan Extra. Buna 85 is a pure butadiene polymer of relatively low molecular weight. Buna S is a mixed polymer of butadiene and styrene. Perbunan is a mixed polymer of butadiene and acrylic nitrile. Perbunan Extra is a mixed polymer of butadiene and acrylic nitrile, but containing a higher proportion of the nitrile than Purbunan. The various techniques useful in the processing and handling of these several products are briefly described.

TNEC Oil Investigation Report is Published

A verbatim record of the proceedings of the Temporary National Economic Committee since the committee began its investigation on December 1, 1938, has been published by The Bureau of National Affairs, 2201 M Street, N. W., Washington, D. C. The volumes contain the full stenographic transcript and all exhibits ordered printed into the records.

Oil was the subject of the hearings during September and October, 1939, and testimony given at that time are contained in Volumes 6, 7 and 8. The price is $6.50 per volume, with a charge of $15 for the three volumes.

TEXACO DEVELOPMENT CORPORATION

PATENT LICENSES IN THE PETROLEUM FIELD

TEXACO DEVELOPMENT CORPORATION

A Subsidiary of The Texas Corporation

26 Journal Square • Jersey City, N. J.

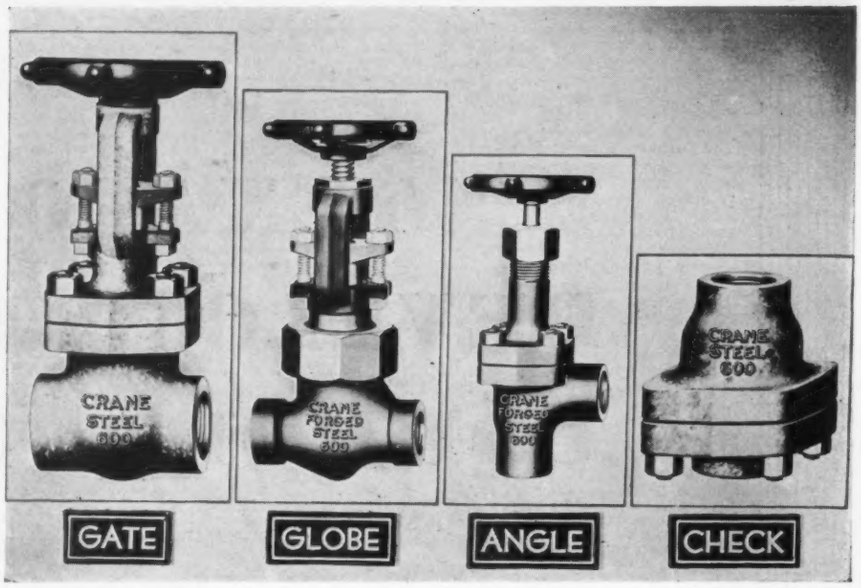
New Equipment for the Modern Plant

Chemodizing
COLONIAL ALLOYS COMPANY

A process for non-electrolytic surfacing of calalloy and its alloys and of aluminum and its alloys has been announced by Colonial Alloys Company, Philadelphia.

The process employs a solution, furnished ready to mix with water for use, in which the metal is immersed. Use of heat is optional, and time range is from 5 minutes to 20 hours. The solution is described as non-toxic, without objectionable odor, as remaining stable when not in use, and as affording no danger to the operator by fumes or spillage.

The resulting surface is described as corrosion-resistant, almost flint-hard, practically colorless and one that will not leave smudge marks when rubbed; as providing an excellent base for paints, lacquers, oils, chemicals, dyes and other sealers and as suitable for impregnating with anti-corrosive materials specifically designed to resist certain types of corrosion.



Crane Company's New Line of Small Steel Valves for Steam and Oil Service

Valves
CRANE COMPANY

A new line of small steel valves for steam and oil service has been announced by Crane Company, Chicago. It includes gate, globe, angle, and check valves in sizes from ¼- to 2-inch and includes both inside screw and O. S. & Y. construction, union and bolted bonnets, screwed, socket weld and flanged ends. The line includes 176 styles and sizes.

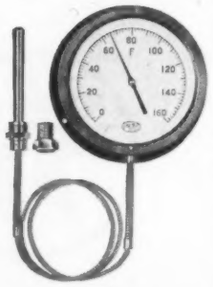
The gate valves are made of cast steel with O. S. & Y. construction, having union bonnet type in screwed ends in sizes ¼- to ¾-inch inclusive, and bolted bonnet with screwed, socket weld and flanged ends in sizes ½- to 2-inch inclusive. The ½- and ¾-inch are available in both union and bolted-bonnet types.

The globe and angle valves are made of forged steel with both inside screw and O. S. & Y. construction. Inside screw valves have screwed ends with union bonnet in sizes ¼- to ¾-inch inclusive, and bolted bonnet in sizes 1- to 2-inch inclusive O. S. & Y. valves have screwed ends with union bonnet in sizes ¼- to ¾-inch inclusive, and screwed, socket weld and flanged ends with bolted bonnet in sizes ½ to 2-inch inclusive. The ½ and ¾-inch are available in both union and bolted bonnet styles.

Check valves are made in two types. The horizontal pattern is forged steel with union cap and screwed ends in sizes ¼ to ¾-inch inclusive, and with bolted cap and screwed, socket weld and flanged ends in sizes ½- to 2-inch inclusive. The ½- and ¾-inch are available in both union and bolted cap styles. The vertical ball pattern is cast steel with bolted joint and screwed ends in sizes ½- to 2-inch inclusive.

Are You Satisfied

That the instruments you now use are the last word in accurate registration of temperature? Do you find the need of a more accurate record?



Palmer Industrial and Laboratory Thermometers, with our patented "Red-Reading-Mercury" feature are known everywhere for sensitive and accurate temperature reading.

The Palmer "Superior" Dial and Recording Thermometers carry this same high standard of quality . . . and you will be amazed at the accuracy and quick reading.

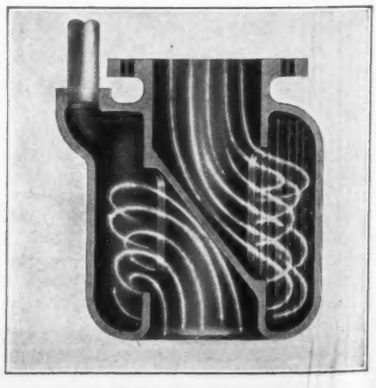
We invite you to be shown
(Bulletin No. 1300—Recording; No. 1500—Dial)

THE PALMER CO.
MANUFACTURERS: INDUSTRIAL, LABORATORY, DIAL AND RECORDING THERMOMETERS
2513 Norwood Ave., Cincinnati, Norwood, Ohio
King and George Sts., Toronto, Canada

Exhaust Head
COCHRANE CORPORATION

An exhaust head designed to insure separation of condensate and oil from steam discharged to the atmosphere, and thereby prevent raining of water and oil condensate upon the roof or ground below, has been announced by Cochrane Corporation, 17th Street and Allegheny Avenue, Philadelphia.

Described as discharging clean, dry steam noiselessly, the exhaust head incorporates principles of the company's



Cochrane Corporation's Exhaust Head

HIGH IN TEMPERATURE RESISTANCE, *BUT NOT IN COST*

As refinery operating temperatures are pushed higher and higher, equipment costs are very apt to mount with them. Frequently, however, they can be held to reasonable levels by the selection of proper material.

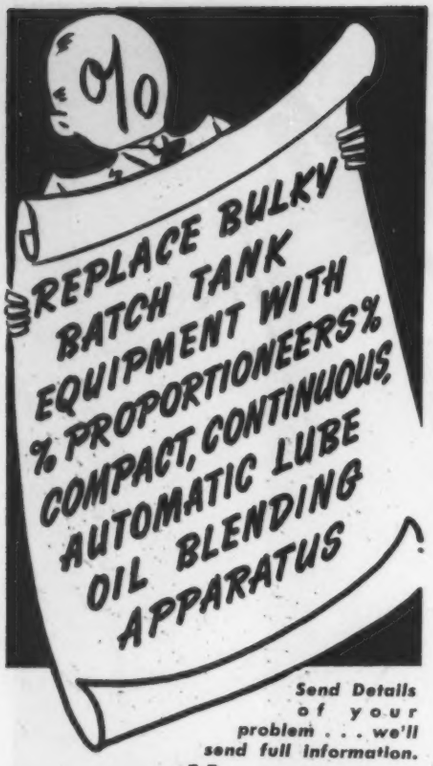
In the case, for example, of high temperature pipe line fittings Carbon-Molybdenum (0.50% Mo) steel is proving an excellent solution to the problem. It retains its strength at temperatures up to 1000° F. In pipes it has sufficient strength to withstand the Bourdon effect without difficulty. And, considering all that it can do to insure uninterrupted operation and reduced maintenance and replacement expense, it is comparatively inexpensive.

Full technical details concerning Carbon-Molybdenum and the various other Molybdenum steels used in refinery operations are contained in our book, "Molybdenum in Steel", which is sent free on request to interested executives and engineers.

PRODUCERS OF MOLYBDENUM BRIQUETTES, FERRO-MOLYBDENUM, AND CALCIUM MOLYBDATE

Climax Mo-lyb-den-um Company
500 Fifth Avenue · New York City

MOLY



Send Details of your problem . . . we'll send full information.

%proportioneers INC.%

31 CODDING ST.,
PROVIDENCE, R. I.

DAVENPORT WOOD SOLES are designed for use where underfoot conditions are too tough for ordinary soles. WOOD SOLES provide safer footing on slippery floors and rough, uneven surfaces. Tough maple soles, cut for comfortable walking, long outwear ordinary soles. It will pay you to investigate DAVENPORT WOOD SOLE SHOES. *WRITE for FREE CATALOG and latest prices!*

F. J. STAHMER SHOE CO.

2351 Boies Ave. Davenport, Iowa

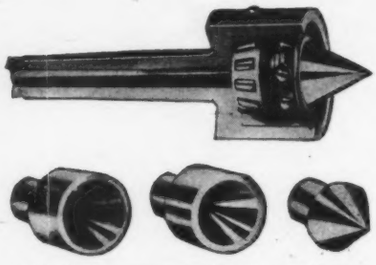
baffle-type steam separators used for removing oil and moisture from steam lines. Port area is provided to produce low steam velocity and minimize pressure loss. Steam is whipped sidewise after passing through port and causes projection of entrainment against ribbed baffle surfaces. The ribbed baffles exert a scrubbing action in addition to the centrifugal purging force.

The exhaust head is of one-piece semi-steel construction for five sizes between 4- and 12-inch, and of welded steel plate construction for 14-, 16- and 20-inch sizes.

Live Center

IDEAL COMMUTATOR DRESSER COMPANY

A new live center with interchangeable inserts or center pieces for holding centered and uncentered work on power lathes has been announced by Ideal Commutator Dresser Company, 1525 Park Avenue, Sycamore, Illinois.



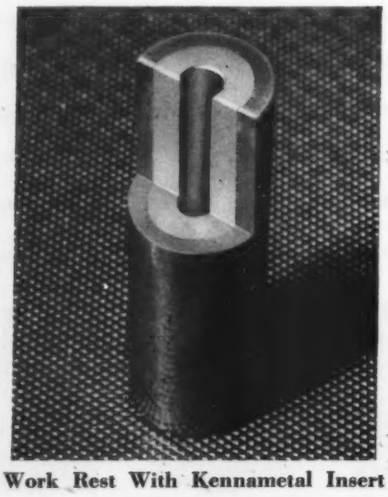
Ideal Commutator's Live Center

Inserts available, which may be used interchangeably, include a male insert for work already centered, plain female insert for uncentered work such as armatures and drills, and female insert with three raised lands for uncentered work having a flat or burred keyway. The inserts are removed by a knockout screw.

Work Supports

McKENNA METALS COMPANY

Work rests for supporting work in machine tools and other metal-working machinery with Kennametal inserts have been announced by McKenna Metals Company, 184 Lloyd Avenue, Latrobe, Pennsylvania. They are made to specification in any length, diameter and bore.



Work Rest With Kennametal Insert

Valve

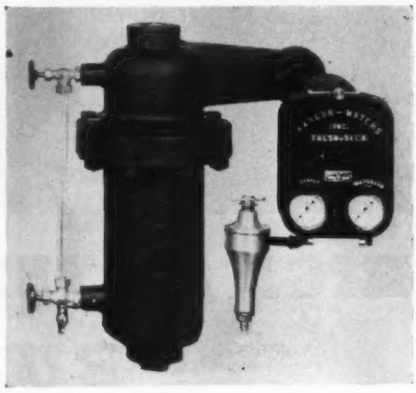
MERCO NORDSTROM VALVE COMPANY

A new Hypreseal production valve of alloy steel designed for extreme conditions of pressure, temperature and abrasion, and rated from 500 to 7500 pounds working pressure, has been announced by Merco Nordstrom Valve Company, Pittsburgh.

The valve utilizes the Sealdport method of lubrication designed to prevent leakage by introduction of a plastic, viscous seal of lubricant between the plug and its seat and to protect the working surfaces from corrosive or erosive action of the line contents. An unbroken seal of lubricant, under pressure, is described as completely sur-

"The Sensation of The Oil Show"

HANLON-WATERS Type 46 Level Controller



● *"An excellent example of really NEW equipment"—is the way one engineer expressed the satisfaction of hundreds who studied this HANLON-WATERS Long Range Level Controller at the Oil Show.*

Especially designed for control of all gravity liquids at high working pressures and temperatures.

● NO STUFFING BOX

NO leakage — NO friction

No fin section for high temperature operation . . . Extremely sensitive . . . All lengths—Any pressure . . . Fabricated to API-ASME specifications.

Learn today about this NEW H-W Type 46 Level Controller, write for complete information and prices.

HANLON-WATERS, INC.

TULSA, OKLAHOMA

Chicago, Pittsburgh, St. Louis, Denver; Shreveport and Lafayette, La.; Fort Worth, Houston, Corpus Christi, Longview and Odessa, Texas

BADGER EXPANSION JOINTS

STAINLESS STEEL — to give resistance to the high temperatures used in refinery process lines

PACKLESS — to eliminate the need for any servicing throughout the life of the joint

COMPACT — to fit into cramped quarters and reduce to a minimum insulation requirements

BADGER engineers developed these expansion joints especially for refinery work. They brought to the design and fabrication of these packless joints more than forty years' continuous experience in pioneering and development. They were responsible for the Directed Flexing feature, a design of corrugation that promotes better flexing action and definitely prevents the localization of flexing stresses, which tends to take place in old-style, straight-sided corrugations.

BADGER Expansion Joints are the experienced and perfected joints. They are the better buy.

E. B. BADGER & SONS CO.

75 PITTS STREET, BOSTON, MASS.
Agents in Principal Cities

rounding both inlet and outlet ports of the valve.

The valve plug is a separate conical member, fitted to its seat in the body. The plug is assembled to the body through the bottom opening which is then closed by a screwed member or sealing plug. Threads are sealed by a plastic packing material applied through circular grooves cut into this screwed member. The function of holding the valve plug in its seat is performed by a spring plate interposed between the threaded bottom member and the bottom of the valve plug. The spring plate is described as unaffected by internal pressure, and at no time is there any fixed clearance between plug and body.

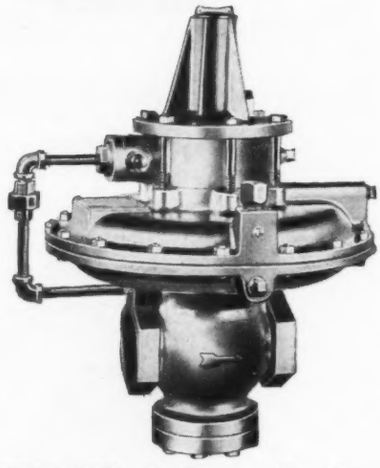
The valve plug is rotated by a separate stem threaded through the upper part of the body. The stem is joined to the plug through a floating equalizer fitting so that the two parts rotate together, but are independent as to lengthwise movement. A secondary seal, which is called upon principally to prevent the slow escape of lubricant past the stem threads, is provided by compressing a plastic fibrous packing material into an annular recess near the outer end of the stem by means of a compression screw and check valve fitting which permits additional packing to be inserted without removing pressure from the valve.

Merco Nordstrom Hypreseal Valve

Pressure Regulator

PITTSBURGH EQUITABLE METER COMPANY

A gas pressure control regulator designed to provide accurate control for installations having both small and large flow rates, where supply pressures ranging up to 150 pounds must be reduced to 20 pounds or less, has been announced by Pittsburgh Equitable Meter Company, 400 North Lexington Avenue, Pittsburgh.



EMCO 1001 Gas Pressure Regulator

Designated EMCO 1001, the regulator features a pilot loading system for diaphragm control to assure movement of the main operating diaphragm with a change in control pressure. The principal is described as assuring maintenance of the desired pressure at a definite and unvarying amount from minimum flow rates to the maximum capacities which can be obtained under the existing pressure conditions.

It is designed for large gas appliances, boiler plants and industrial heat-treating furnaces.

Acid Sludge Mill

VOLCANIC SPECIALTIES COMPANY

Volcanic Specialties Company, Alliance, Ohio, is offering an acid sludge mill for converting acid sludge and heavy fuel oil into plant fuel. If necessary, the sludge is cooked until it can be pumped and mixed with the required oil carrier. The mixture is then pumped through the mill, which cuts, macerates, grinds and mixes the oil and sludge into a flowing blend ready for the fuel system.

Literature of the manufacturer describes the mill as:

"A series of saws and spacers revolve within a housing divided into eight attrition chambers, through which the oil sludge is pumped from the inlet over and around to the discharge outlet. The work is therefore accomplished in eight separate stages and

A Wilson "Matched Unit"—An E P (Extra Power) Heavy Duty Motor and an FPT Cutter Head.

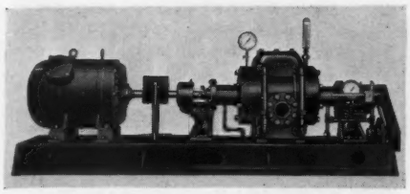
YOU GET EXTRA POWER WITH WILSON CLEANERS

Power **in tube cleaning motors reduces "down time," labor and overhead costs and gives you a quicker, better and more economical cleaning job.**

Wilson E P (Extra Power) Heavy Duty Air Motors develop from 30% to 75% ***more power*** **but use from 25% to 40%** ***less air*** **than ordinary tube cleaning motors of the same size. They were designed for use where very hard or very heavy deposits must be removed. For speedy, safe and satisfactory tube cleaning, Wilson E P (Extra Power) motors and Wilson cutter heads and accessories are unexcelled.**

Send for a copy of our new thirty-six page catalog fully describing and illustrating the complete line of Wilson tube cleaning equipment.

THOMAS C. WILSON, Inc.
PIPE AND TUBE CLEANERS EXCLUSIVELY
47-28 37th Street Long Island City, N. Y.



Volcanic Acid Sludge Mill

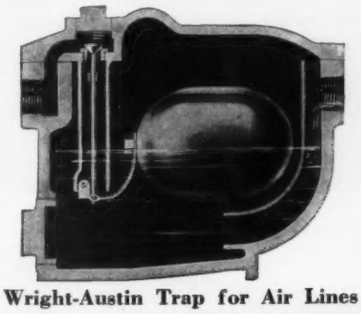
with no close clearances or rubbing surfaces.

"A spinning motion of the oil and sludge is set up in each chamber and with sufficient velocity to automatically separate the heavier particles by centrifugal force and the result is a high frequency contact with the running saws. The particles and masses are actually milled to a minute grain size and all soluble substance reduced to a solution, while the insolubles become finely divided suspensoids."

Air Line Trap

WRIGHT-AUSTIN COMPANY

A new trap for draining moisture and oil from compressed air equipment has been announced by Wright-Austin Company, 315 West Woodbridge Street, Detroit.



Wright-Austin Trap for Air Lines

The trap is designed to handle thick oily emulsion from cylinder lubrication satisfactorily because of a large outward opening valve, and to operate from a closed position without priming as the valve is closed when the trap is empty.

The valve opens outward, above the seat and in the same direction as the outgoing flow of condensate, to permit a large orifice that will promote a free flow of cold gummy oil in the water from the compressed air without choking up the trap.

The trap is of the float type. Working parts are removable by lifting the cover. It is unnecessary to break inlet and outlet connections.

Welding Control

WILSON WELDER & METALS COMPANY

A new automatic start and stop device for use on any magnetic starter, motor generator arc welder driven by an A. C. motor has been announced by Wilson Welder & Metals Company, 60 East 42 Street, New York. The device is intended to eliminate waste incurred from frequent idling of an arc welder between jobs.

The welding unit equipped with the device is started by the operator when he touches the work with his electrode. As long as the operator is welding, the unit keeps running. When welding is interrupted, the machine automatically stops after a time delay that may be set between ½ and 1½ minutes. The time delay is intended to prevent undesirable frequent stoppings in case of a tacking job.

The device is reconnectable for 220 or 440 volts, and it is supplied for other A. C. voltages in 60 cycles.

Clutch Facings

THE GATKE CORPORATION

New clutch facings with integrally-moulded gear teeth and designed for heavy-duty applications have been announced by The Gatke Corporation, Chicago.

The teeth are moulded the full thickness of the facing to increase the wear area and eliminate wear to the housing. The facings are furnished in all sizes up to 30 inches in diameter.

Reversible Wrenches

CHICAGO PNEUMATIC TOOL COMPANY

Two new power vane reversible wrenches have been announced by Chicago Pneumatic Tool Company, 6 East 44 Street, New York. The wrenches, similar in construction, employ a slow-speed rotary motor and have no gears or resilient member in the driving unit. They are designed especially for removing or applying staybolt caps, dome nuts, smoke box nuts, cylinder and valve chamber head nuts, front end nuts, washout plugs, and structural

"INSTALLED IN 1932, This STERLING Turbine Pump IN PERFECT CONDITION TODAY!"

Read This Excerpt from a Letter of J. L. Biddle, Supt. of Maintenance, WESTVACO CHLORINE PRODUCTS, INC.

"We installed the first Sterling Turbine Pump in 1932 at 500' setting. This pump has been in continuous service since that date except when we pulled the well to inspect the pump and lower pump to 700' setting. On May 26, this year (1936), we again pulled this pump to inspect it, and again found it to be in perfect shape.

"Since 1932 we have installed many more of the same type of Sterling pumps . . . we are 100% sold on them!"

Such a statement by a man of authority who has no personal axe to grind should mean much to you who seek long-lived, trouble-free operation. Write for full details, catalogs and prices, today.

PRECISION BUILT

STERLING PUMP CORPORATION

HAMILTON, OHIO STOCKTON, CALIF.

STERLING

DEEP WELL TURBINE PUMPS

Few Sterling Pump owners need service—but if you need it, Sterling offers the highest class of service from coast to coast.

"VULCAN SUPERIOR" TONGS handle BOTH pipe and fittings

Here is the unbeatable tongs for Refinery use.

"Vulcan Superior" is a universal service tongs for both pipe and fittings—TWO tools in one. You can switch from one to the other *instantly*—no parts to change, no adjustments to make. Seven sizes, with either flat link or cable chain, handle pipe and fittings from ⅛ to 12 inches. Fully guaranteed. Write for complete Williams' catalog or see our advertisement in the Composite Catalog. Buy from your supply store.

J. H. WILLIAMS & CO.
225 LAFAYETTE ST. NEW YORK

Headquarters for: Drop-Forged Wrenches (Carbon and Alloy), Detachable Socket Wrenches, Reversible Ratchet Wrenches, Tool Holders, "C" Clamps, Lathe Dogs, Eye Bolts, Hoist Hooks, Thumb Nuts and Screws, Chain Pipe Tongs and Vises, etc., etc.

WILLIAMS
SUPERIOR DROP FORGED TOOLS
VULCAN SUPERIOR
PIPE AND FITTINGS TONGS

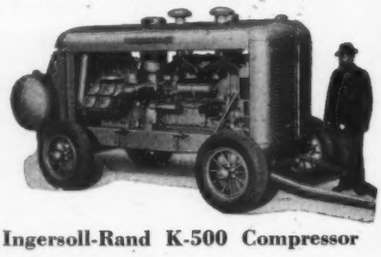
CP 365-R Reversible Wrench

steel work. Model CP 365-R has a capacity of 1¼ inches bolt size, and model CP 375-R has a capacity of 1¾ inches bolt size.

Portable Compressor

INGERSOLL-RAND COMPANY

A new portable compressor designed to deliver 500 cubic feet per minute at 100 pounds pressure has been announced by Ingersoll-Rand Company, 11 North Broadway, New York.



Ingersoll-Rand K-500 Compressor

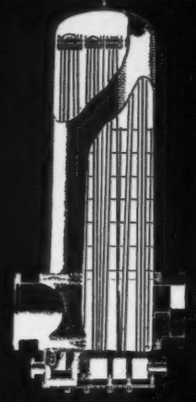
The compressor, designated Model K-500, is powered by either an oil engine or a new-type 6-cylinder gasoline engine that does not require high-grade motor gasoline. It features replaceable cylinder liners for engines and a patented automatic fuel saver to change the engine speed according to use of compressed air. The unit is offered with either wheel- or skid-mounting.

Smoke Alarm

PHOTOSWITCH INCORPORATED

Photoelectric control of combustion conditions is provided by the electric eye smoke alarm with densometer announced by Photoswitch Incorporated, 21 Chestnut Street, Cambridge, Massachusetts. The equipment continuously observes the smoke passing through the flue. It indicates the smoke density on a 4⅜-inch dial which reads from zero to 100. The equipment is set so

LEACH
FRACTO
CONDENSERS
for High Pressure and Temperature.

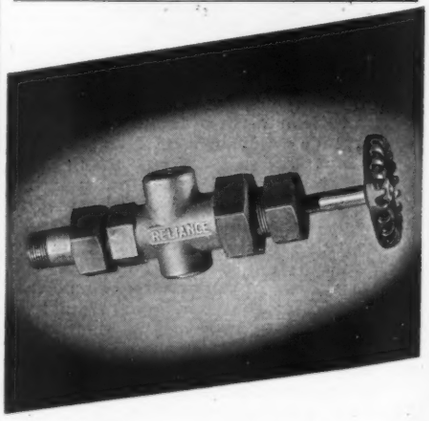


Also Heat Exchangers for Vacuum and Atmospheric Service.

Fracto Control

Patented in the United States and Foreign Countries.

C. H. LEACH CO., Inc.
117 Liberty Street, New York, N. Y.

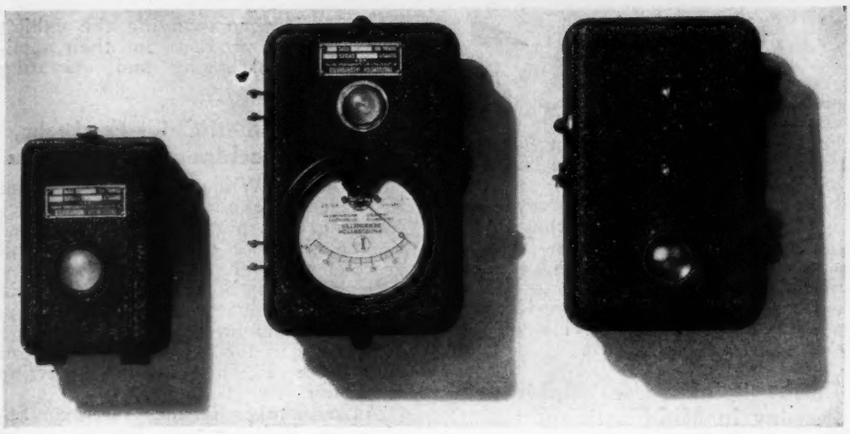


Reliance Steel Valves
save you money in upkeep expense

They're unusually sturdy; bodies of forged steel, quick-closing triple-thread stems, long-wearing stainless seats and discs. Ample packing box proportions assure leak-proof operation. Reliance Steel Valves are trouble-proof on all types of pressure vessels, as thousands in use have proved. Write today for full information.

The Reliance Gauge Column Company
5902 Carnegie Avenue Cleveland, Ohio

Reliance



Photoswitch Smoke Alarm, consisting of photoelectric control, densometer-signal combination and light source.

that a large red signal light indicates when the smoke density exceeds a predetermined value consistent with efficient combustion.

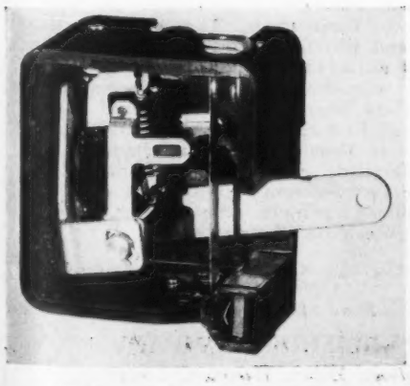
Photoswitch smoke alarm consists of photoelectric control, densometer-signal combination and light source. The light source and photoelectric control are mounted on opposite sides of the flue or breaching, and are aligned through simple entrance tubes or windows so that the beam projected from the light source strikes the eye of the control. The densometer may be placed at any convenient location in the boiler room, usually near the other furnace controls, and is wired to the photoelectric control. All equipment is supplied in dustproof housings, finished in dark green crystal.

Float Switch

GENERAL ELECTRIC COMPANY

A new float switch designed for domestic sump-pump control has been announced by General Electric Company, Schenectady, New York. It is a single-pole switch employing an over-center toggle mechanism. Float-rod weight is counter-balanced by a calibrated spring acting on the operating lever.

Corrosion-resistant parts in the mechanism are intended to permit operation under severe moisture conditions. Other features include accessible terminals for easy wiring, a dummy terminal to provide convenient wiring of the through side of the line, fine-silver contact tips and snap-action mechanism.



GE Sump-Pump Float-Switch

Strainer

WRIGHT-AUSTIN COMPANY

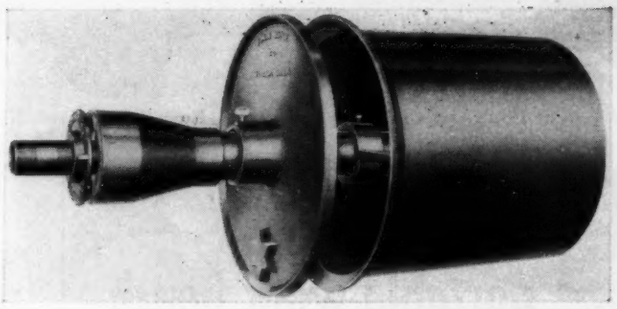
A new strainer, designated Easyclean, for use on steam, oil and compressed air lines to power and industrial equipment and designed to prolong the life of steam traps, pressure reducing valves and similar units, has been announced by Wright-Austin Company, 315 West Woodbridge Street, Detroit.

The unit is connected as a union in a pipe line, and has a pocket designed to collect dirt and scale before reaching the screen. The screen is perforated brass having 400 1/32-inch holes per square inch, and the body is cast semi-steel designed for working pressures up to 250 pounds.

The strainer is available in ½-, ¾-, 1-, 1¼-, 1½- and 2-inch sizes.

"SHORTEST FLAME BURNERS IN AMERICA"

Easiest to Buy
Easiest to Install
Easiest to Maintain



No. 14 JOHN ZINK BURNER

Capacity 5,000,000 B.t.u. per hr.
Draft .15-inch. Price $40.00 f.o.b.
Tulsa, Okla. Shipping Wt. 110 lbs.

JOHN ZINK BURNERS

JOHN ZINK COMPANY

Burners • Floor Furnaces • Unit Heaters

TULSA, OKLA. NEW YORK CITY

BUSINESS NOTES

Changes Made in Officers of E. I. du Pont de Nemours

Pierre S. du Pont retired as chairman of the board and Lammot du Pont resigned as president of E. I. du Pont de Nemours & Company at a meeting of the board of directors last week.

Lammot du Pont was elected chairman of the board, and Walter S. Carpenter, Jr., a vice president, was made president of the company.

Lammot du Pont also retired as chairman and a member of the executive committee. Carpenter, vice chairman of the committee, succeeded him to the chairmanship. The vice chairmanship was not filled, and the membership was reduced from nine to eight.

Irenee du Pont, a former president of the company, resigned as vice chairman of the board, and no appointment was immediately made to this position. He, as well as Pierre S. du Pont, will continue as members of the board and of the finance committee, on which Lammot du Pont also will serve.

Carpenter resigned as chairman of the finance committee. Angus B. Echols, a vice president, was elected chairman of the committee. J. B. Eliason, treasurer, was elected a vice president and a member of the board. He will continue as treasurer.

Lunkenheimer Uses Mobile Display in Mid-Continent

The Lunkenheimer Company has started a truck displaying its line of valves and specialties on a tour of the Mid-Continent area. A company representative is accompanying the exhibit to explain the products and their application to purchasing and operating executives.

The Lunkenheimer Company's Display on Wheels, Now Touring the Mid-Continent

Bergdoll Named Chief Engineer, York Ice Machinery Corporation

Llewellyn Williams, vice president in charge of engineering for York Ice Machinery Corporation, has announced the appointment of John G. Bergdoll as chief engineer.

Bergdoll was born in Philadelphia in 1898. He graduated with a degree in mechanical engineering from Lehigh University in 1920 and is a member of Tau Beta Pi, honorary engineering fraternity.

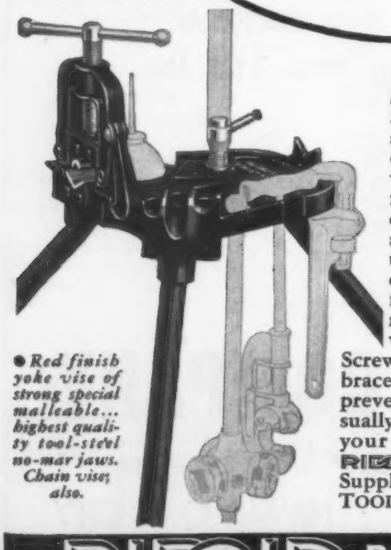
As a member of the American Society of Refrigerating Engineers, he has served on the Expansion Valve Committee, the Standard Condensing Unit Rating Committee, the A.S.R.E. Council and as chairman of the A.S.R.E. Technical Committee on Industrial Applications.

Yale & Towne Advances Morgan To Philadelphia Plant Manager

The Yale & Towne Manufacturing Company, Philadelphia, has advanced James C. Morgan from general sales manager of its Philadelphia division to general manager of the Philadelphia plant.

Morgan came to the company in 1920 from C. B. Hunt Company to take charge of electric truck sales. Electric truck and hoist divisions were later combined in one unit under his supervision.

Gives you a portable work bench— New RIGID Tri-Stand Vise



● *Red finish yoke vise of strong special malleable... highest quality tool-steel no-mar jaws. Chain vise, also.*

A remarkable work-saver, this new RIGID Tri-Stand really gives you a complete work bench, quickly set up where the work is. Its hinged legs fold in and chain for easy carrying. Nothing stingy about it — wide roomy tray for dope pot and oil can, special rim and slots for holding tools, a pipe rest and 3 benders that won't collapse pipe. Screw-down feet and ceiling brace, but it's well balanced to prevent tipping. For an unusually handy tool and more for your money... buy the new RIGID Tri-Stand at your Supply House.... THE RIDGE TOOL CO., ELYRIA, OHIO

RIGID PIPE TOOLS

THE SCIENTIFIC PRINCIPLES OF PETROLEUM TECHNOLOGY

By DR. LEO GURWITSCH *and* HAROLD MOORE

Not only advanced technical and scientific facts, but the necessary elementary principles are reviewed for you in these pages. They contain all the chemistry and physical chemistry that is required. This is an advanced book and yet you need not refer elsewhere for any information about hydrocarbon chemistry or fractional distillation. You will find all this basic scientific information right in these pages. It is cited from the original references, so that you can instantly locate the pertinent reference giving full details on the specialized subject. Systematize your knowledge of petroleum chemistry.

556 Pages, Cloth, 5½ x 8¼, Illustrated, $9.00

Send check to

GULF PUBLISHING COMPANY
3301 Buffalo Drive, Houston, Texas